Joint Command & Control Ship
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Literature Survey on Motion Effects and Related Environmental Effects on Personnel

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The JCC(X) is being designed to be a command and control ship that will house command staff who will plan and execute levels of conflict ranging from Operations Other than War through Major Regional Conflicts. The command staff will be composed of military and civilian personnel from the armed services of the United States and its allies, as well as personnel from other international agencies and organizations. In terms of human factors, the critical issue is that these key individuals will be exposed to stressors, such as motion sickness, that could cause degradations of cognitive or physical performance or both, with a potentially damaging effect on the success of the mission. This report consists of a Literature Survey of research conducted on the impact of ship motions on the cognitive and physical performance of humans.

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INTRODUCTION

The JCC(X) is being designed to be a command and control ship that will house Department of Defense command staff who will plan and execute any level of conflict that is required from Operations Other than War through Major Regional Conflicts. The command staff members will be selected from many diverse sources. These may include military and civilian personnel from both the armed services of the United States and its allies, as well as from other international agencies and organizations. From the point of view of human factors, the critical issue is that many of these individuals may not be familiar with many of the stressors to which they could be exposed, ranging from environmental extremes to outright aggression. At the very least, those who are inexperienced seafarers will require time to adapt to the unfamiliar ship motions unless some action has been taken to address this issue ahead of time. Depending upon the nature of the unfamiliar stressors, many of these key personnel may suffer from degradations of cognitive or physical performance or both, with a potentially damaging effect on the success of the mission.

PREFACE

Ship Motion Effects and the JCC(X)

The problems of ship motion on personnel can have a profound effect on the operational effectiveness of any given mission. Perhaps the most obvious of these effects, namely motion sickness, has been documented throughout history. Motion sickness is not a disease, nor is it a sign of physical or mental weakness. Many bold and courageous people have suffered greatly from this condition, such as:

- Julius Caesar;
- The Spanish Conquistadors and the Portuguese mariners who sailed around the world;
- Lawrence of Arabia suffered from “camel sickness”;
- Lord Nelson, and many of his admirals, suffered from chronic seasickness even on his last voyage;
- Charles Darwin, the famous naturalist, hated the sea because of severe and chronic seasickness;
- Houdini, the famous escape artist, could not escape seasickness; and
- Seasickness severely hampered efficiency during D-Day landings.

Recently, scientific investigation into this issue has been undertaken, in addition to the anecdotal information from the experiences of sailors. It is essential that motion sickness and the potential solutions be addressed to manage and reduce the risk associated with the deleterious effects on Mission Performance.

This is not the only motion effect that degrades performance, however. As we shall see, there are many others. These include incapacitation and fatigue which can have an adverse effect on accomplishing essential naval missions in general and the JCC(X) missions in particular. The JCC(X) will have 1. a high technology embarked crew having C4SIR responsibilities for multi-national Joint command and control of the most militarily important “situational areas” existing at a specific a time and place, and 2. an embarked crew primarily composed of personnel who have not had an opportunity for habituation to a ship motion environment.

JCC(X) ship design management therefore decided to review this area and requested problem definitions, potential solutions and a scientific literature review with respect to these considerations. NSWCCD chose to utilize Dr. Thomas Dobie and his staff at the National Biodynamics Laboratory, (formerly the Naval Biodynamics Laboratory), the nation’s premier organization dealing with motion sickness, for this task. Examples of both survey and performance studies are presented to enhance the discussion of specific issues in each section and an extensive bibliography is presented at the end of each section.

Motion sickness is not only a concern of the JCC(X) but is a current research area being investigated under the Human and Medical Sciences areas of ONR, as well as numerous international organizations such as the ABCD group and NATO. In recent efforts at ONR under LCDR Dylan Schmorrow , CAPT (ret) Dennis McBride suggested that the mechanisms for solutions lie in the areas of Personnel Selection, Treatment, Training, and Design. Applicable solutions will be discussed within this paper including VE and habituation training.

The issues of incapacitation are complex and revolve around a number of ship motions, physiological and behavioral interactions. Areas of particular concern to the JCC(X) such as effects on cognitive performance and motor control and coordination are treated in separate sections. In addition, motion induced fatigue and fatigue effects such as the “sopite syndrome” are also considered. Suggestions for further work are addressed in each section and include further tailoring the considerations raised in this paper to the JCC(X) ship design characteristics as they become more definitive.

1. Motion Sickness

Executive Summary

From a human factors point of view, one of the primary concerns in the development of modern vessels is the degree to which debilitating motion sickness will be encountered by operators and passengers. With current capabilities for simulating ship motions associated with any particular vessel, it is possible to evaluate the degree of motion sickness to be expected in various sea states and at different locations aboard the vessel in question. The first order of business is to determine the scope of the problem by determining the severity of motion sickness in simulations of JCC(X) type vessels. In this regard, other factors like the sex and age of the person might also be considered. An appropriate second step would be to evaluate the effectiveness of current pharmacological interventions to handle problems in the short term. These potential preventive steps might also be used in conjunction with cognitive/behavioral techniques in an effort to facilitate adaptation to motion environments. Recommendations concerning such evaluations are suggested.

1a. Motion Sickness – General

Introduction

Motion sickness is a response to real or apparent motion to which a person is not adapted. It is characterized by malaise, general discomfort, pallor, sweating, nausea and vomiting. Provocative motion environments involve many forms of transport, such as ships, aircraft, air cushion vehicles and automobiles, all of which are important to the Navy. Motion sickness is also experienced in flight simulators and the microgravity of space shuttle missions. The characteristics of the underlying stimuli are essentially the same, however, and so are the subjective responses. It is for this very reason that the responses have all been labeled *motion sickness*.[1] It should also be noted that motion sickness can also be produced in the absence of expected motion. Visual motion alone is sufficient to produce sickness,[2] as in the case of fixed-base simulators or when viewing wide-screen movies.

Symptoms and Signs of Motion Sickness

The main symptom of motion sickness is nausea[3] and the main signs are pallor, sweating and vomiting. However, many responses are reported to varying degrees, such as apathy, general discomfort, headache, stomach awareness, increased salivation and prostration. Other less common responses include drowsiness, frontal headache and hyperventilation.[4] More recently some evidence has been gathered that suggests that the pattern of symptomatology may differ according to the type of stimulus. For example, Kennedy, Dunlap and Fowlkes[5] pointed out that visually related disturbances are more prevalent in simulator sickness than are gastrointestinal disturbances. Perhaps this is not surprising in view of the type of stimulation. A summary of the physiological correlates associated with motion sickness is included in Table 1.

Table 1
Motion Sickness Responses

Physiological Systems	Responses
Cardiovascular	Changes in pulse rate and/or blood pressure. • tone of arterial portion of capillaries in the nail bed. diameter of retinal vessels. peripheral circulation, especially in the scalp. • muscle blood flow.
Respiratory	Alterations in respiratory rate. Sighing or yawning.
Gastrointestinal	Inhibition of gastric intestinal tone and secretions. Salivation. Belching. Epigastric discomfort or awareness. Sudden relief from symptoms after vomiting.
Body fluids, Blood	Changes in LDH concentrations. • hemoglobin concentration. • pH and Pa_{CO2} levels in arterial blood, presumably from hyperventilation. concentration of eosinophils. • 17-hydroxycorticosteroids. • plasma proteins.
Urine	• 17-hydroxycorticosteroids. • catecholamines.
Temperature	• body temperature. Coldness of extremities.
Visual System	Ocular imbalance. Dilated pupils during emesis. Small pupils.
Behavioral	Apathy, lethargy, sleepiness, fatigue, weakness. Depression and/or anxiety. Mental confusion, spatial disorientation, dizziness, giddiness. Anorexia, unusual sensitivity to repulsive sights or odors, or excessive discomfort from previously tolerable stimuli such as heat, cold, or tightness of clothing. Headache, especially frontal headache. • muscular coordination and psychomotor performance. • time estimation. • motivation.

Incidence of Motion Sickness

The incidence of motion sickness is extremely variable depending upon the circumstances. Only persons who lack a functional vestibular system are immune to motion sickness. In 1964, Walters reported on a study in the British Royal Navy in which medical officers indicated the number of cases of seasickness on each day at sea, together with relevant information on sea conditions.[6] He considered that the figures were conservative because they did not include those who did not report sick, despite feeling ill. Nor did they include those individuals who, being aware of their susceptibility to sea sickness, took medication that they knew to be effective in their case. The study included the crews of 5 small ships that together spent a total of 93 days at sea in the North Atlantic during the autumn of 1963. Overall, they contributed 8,628 man-days of sea experience in weather conditions that varied from flat calm to full gale. Their experience with seasickness is shown in Table 2. This shows that, out of a total of 8,628 man-days at sea, the crews suffered seasickness of one degree or another, and were rendered less efficient as a consequence, for 1179 man-days (13.7). During these days at sea, 26 were calm, 26 were moderately rough and 41 rough. The figures for the incidence of seasickness related to these weather conditions are shown in Table 3, where it can be seen that in rough seas 26.5 % of crew members were seasick. During those cruises that lasted 4 or more days in moderately rough or worse weather, Walters reported on the apparent habituation to motion that occurred (Table 4). This question of habituation, as it refers to the JCC(X) situation, will be addressed later when discussing motion sickness prevention.

Table 2. Overall loss of efficiency due to sea-sickness in men at sea (all weathers)

Total Days at Sea	Total Man-days of Experience	Number Unaffected (Man-Days)	Number Affected but not Vomiting (Man-Days)	Number Vomiting (Man-Days)	Number Incapacitated (Man-Days)
93	8628 (100%)	7449 (88.3%)	1060 (12.3%)	105 (1.2%)	14 (0.2%)

Table 3. Sea-sickness and weather

Sea-sickness and weather	*Calm*	*Moderately Rough*	*Rough*
No. of men affected by sea-sickness in any way (man-days) No. of man-days spent in a given weather condition	0.2%	3.6%	26.5%

Table 4. Cruising in rough weather

Day of Cruise	Percentage of men affected by sea-sickness in any way
1	21.9%
2	19.9%
3	18.4%
4	13.2%
5	4.4%

Hill[7] estimated that over 90% of inexperienced passengers become seasick in very rough conditions and some 25%-30% during the first two or three days in moderate seas. Chinn[8] reported that during the first two or three days of an Atlantic crossing, in moderate seas, 25%-30% of passengers on liners become seasick. Lawther and Griffin[9] conducted a questionnaire survey of motion sickness occurring on board passenger ferries. Data were collected from 20,029 passengers on 114 voyages on 9 vessels: 6 ships, 2 hovercraft, and 1 jetfoil. For an initial examination of the data, they pooled the results over all voyages and all vessels and found that 7% of the passengers vomited at some time during the journey; 21.3% felt "slightly unwell", 4.3% felt "quite ill", and 4.1% felt "absolutely dreadful."

In terms of airsickness, Rubin[10] quoted an incidence of 11% (ranging from 6% to 22% with different training courses) during basic flight training. A survey of flight instructors' post-flight reports showed that 38.7% of 577 RAF flight trainees suffered from airsickness at some time during their basic flight training on single-engine jet aircraft, usually in the early stages.[11] In more than a third of these cases airsickness was severe and protracted and had a detrimental effect on training effectiveness or caused sorties to be abandoned altogether. A study of US Navy officers undergoing flight training for various non-pilot crew duties revealed a mean incidence of airsickness in 13.5% of all flights. This was judged to have caused a decrement in trainee performance in 7.3% of flights.[12]

In other forms of transport the situation is similar, but it is difficult to give a precise figure for the incidence of motion sickness because, as is the case with almost all maladies, it depends on a number of factors, for example:

- The characteristics of the stimulus in terms of frequency, intensity, direction and duration. Experiments on vertical oscillators, which simulate the heave component of ship motion, have shown that the incidence increases as the frequency of oscillation falls. The most provocative frequency was shown to be 0.2 Hz.[13,14]
- The susceptibility of the individual, based upon physiological characteristics, past experiences and personality factors.
- Individual activity at the time of exposure to the stimulus; e.g. passengers are usually worse off than drivers.
- Other factors, such as food and certain smells.

Tyler and Bard[15] reported that motion sickness varies with age. Susceptibility appears to be at its highest between 2 and 12 years of age and Reason[16] reported that a significant decline follows between the ages of 12 and 21. The incidence of motion sickness continues to diminish beyond that age and is very low in the elderly. More recently, however, Cheung and Money[17] have pointed out that squirrel monkeys undergo no change in susceptibility to motion sickness with increasing age. These researchers suggest that it is not age that affects susceptibility, but the development of behavioral strategies for coping with different types of provocative motion.

Sex Differences

Reason reported that in a questionnaire study among students, women declared a significantly higher incidence of motion sickness than men of similar age and travel experience at all ages, that is, before and after the age of twelve years. Nieuwenhuijsen[18] carried out a survey of 193 passengers who were crossing the Atlantic Ocean by ship and found that the ratio of male to female susceptibility to seasickness was of the order of 2:3. Lawther and Griffin[9] carried out a survey of over 20,000 passengers on ferries crossing the English Channel and these reports indicated that the females were more susceptible to seasickness than males. In their study, the ratio was 3:5 in terms of reported incidence of vomiting in all age groups over 15 years. These responses indicated that this difference, between men and women, in the ratio of susceptibility to motion sickness, age for age, is of the order of 1:1.7 which is very similar to Nieuwenhuijsen's findings.

Benson[19] stated that the reason for this sex difference, which is applicable to both children and adults, was not known. However, he suggested that perhaps females are more ready to admit to having had symptoms of motion sickness. On the other hand, it may be that some males are less likely to admit their susceptibility because of their wish to exhibit a macho image. Perhaps experience also plays a part, because males tend to exhibit a more "rough and tumble lifestyle" which may provide some protection against provocative motion.

On the other hand, repetitive exposure to provocative motion in automobiles does not prevent individuals from continuing to suffer from motion sickness, so the question of experience remains open.

Recently, Dobie et al.[20] carried out a questionnaire study into the effects of sex, age and physical activities on susceptibility to motion sickness. This revealed significantly greater motion sickness for female when compared to male subjects on devices with which both groups were equivalent in terms of their exposure history. In addition, the study demonstrated little relationship between an individual's level of physical activity and their susceptibility. In other words, we were unable to show any evidence of either habituation or sensitivity caused by participation in any of the 17 leisure and sporting activities that were surveyed. There was also little evidence to suggest that males are more reticent to report motion sickness.

Reason and Brand[3] believed that certain factors could be excluded in terms of explaining this sex difference. For example, they were of the opinion that there was no reason to believe that females showed a greater sensory response to the nauseogenic features of provocative motion. They also stated that there was no evidence that their ability to adapt was any different from that of men.

Schwab[21] pointed out that in the adult female, hormonal factors may be implicated since susceptibility to motion sickness is reported to be highest during menstruation and increased in pregnancy. On the other hand, Reason[16] found, as stated above, that there was a difference between males and females even before the age of twelve years.

Grunfeld et al.[22] carried out a questionnaire study of motion sickness during the 1997 British Telecom yacht race ("Global Challenge") which consisted of six legs varying from 8 to 45 days. Many of the sailors were seasick at some time during the race. Daily logs were kept by 25 men and 27 women in which they recorded any headache or symptoms of seasickness and the women additionally took note of the dates of their menstrual periods. Female crewmembers were found to be most susceptible to seasickness from 3 days before the onset of menstruation to the fifth day after. Headache was also at its greatest during that same time period. On the other hand they reported that the incidence of seasickness was at its lowest around the time of ovulation, but headache again peaked at that time. These results lend credence to the idea of a possible link between motion sickness and hormonal changes.

The main difference in the incidence of motion sickness among individuals exposed to identical motion stimuli could be physiological, but more likely is due to the personal experiences of these individuals in these environments and how they react to them. These experiences include practice, attitude of mind and levels of mental arousal. On the one hand, passengers have been known to report that they feel sick before the ship leaves the dock. Others claim that they never get sick at sea “whatever the weather”, but cannot cope with the movements of fairground devices. There are many seeming anomalies in individual histories. Perhaps these differences in response to provocative motion are determined by where a particular person lies along the underlying causative psycho-physiological spectrum, which can vary from individual to individual and device to device with differing attitudes and amounts of arousal.

Physiological Mechanisms Underlying Motion Sickness

The currently most acceptable explanation of motion sickness is that the physiological component is the body's response to inharmonious sensory information reaching the so-called *comparator* in the brain. The motion stimuli originating from active or passive bodily motion are mainly detected by the eyes and the vestibular apparatus. Additionally, however, changes in the body's orientation to the gravitational field and other added linear accelerations can also stimulate mechanoreceptors located in the skin, muscles, joints and other tissues. Passive provocative stimuli are caused by the body being moved by some form of vehicular motion. In addition, an active component may be caused by bodily movement, such as moving the head, which also affects the vestibular apparatus. The restriction of head movement has already been used as a means of preventing airsickness.[23]

This physiological explanation for motion sickness is called *the neural mismatch hypothesis*, indicating that there is some sustained dysynchrony at the level of the comparator in the brain.[24,25] Not only might the incoming signals be in conflict with each other, but they might also be in disagreement with those the brain expects to receive. (Figure 1).

The two main types of sensory conflict can be described according to the receptors involved: visual-inertial rearrangements and (semicircular) canal-otolith rearrangements. In each case, two types of conflict can occur. In the first, known as type 1, both systems signal contradicting or uncorrelated information at the same time. In the second, known as type 2, when one system is sending information there is an absence of the expected signal from the other. The human body is designed for walking, running or jumping on the surface of the earth. During these natural maneuvers, the main frequencies reaching the head lie somewhere between 0.5 to 10 Hz, so linear oscillation at 1 Hz doesn't produce motion sickness. On the other hand, oscillation at 0.2 Hz is highly provocative and this is probably due to the nature of the "engram", based on canal/otolithic activity, which has been established during these locomotor activities on earth.[26] Although this neural mismatch theory is widely accepted, there are other etiological theories, such as the subjective vertical conflict theory,[27] the postural instability theory[28] and a nystagmus hypothesis.[29]

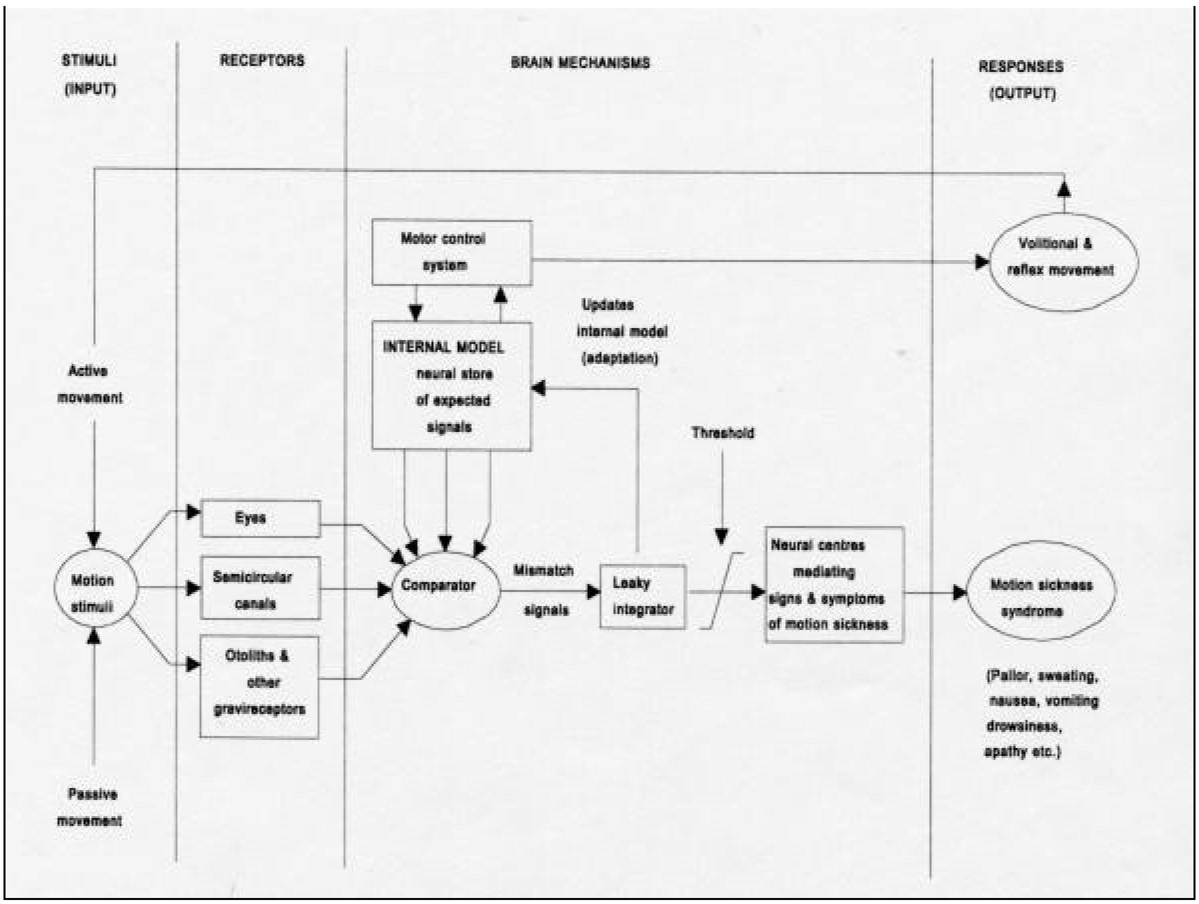

Figure 1. Diagrammatic Representation of the Physiological Model of Motion Sickness (Benson, 1984)

Psychological Mechanisms that Exacerbate Motion Sickness

There is also a psychological component to the causation of motion sickness. It is natural to develop an anxiety due to feelings of discomfort or nausea brought about by certain provocative maneuvers, or when exposed to a different and unfamiliar mode of travel. This is due to the arousal that typically develops when one is exposed to situations known to be uncomfortable or threatening. The magnitude of this anxiety is also likely to be determined by an individual's personality.

In summary, the underlying cause of motion sickness is likely to be a form of neural mismatch, together with experiential anxiety caused by that individual's attitudes, memories and past experiences with motion stimuli. (Figure 2).

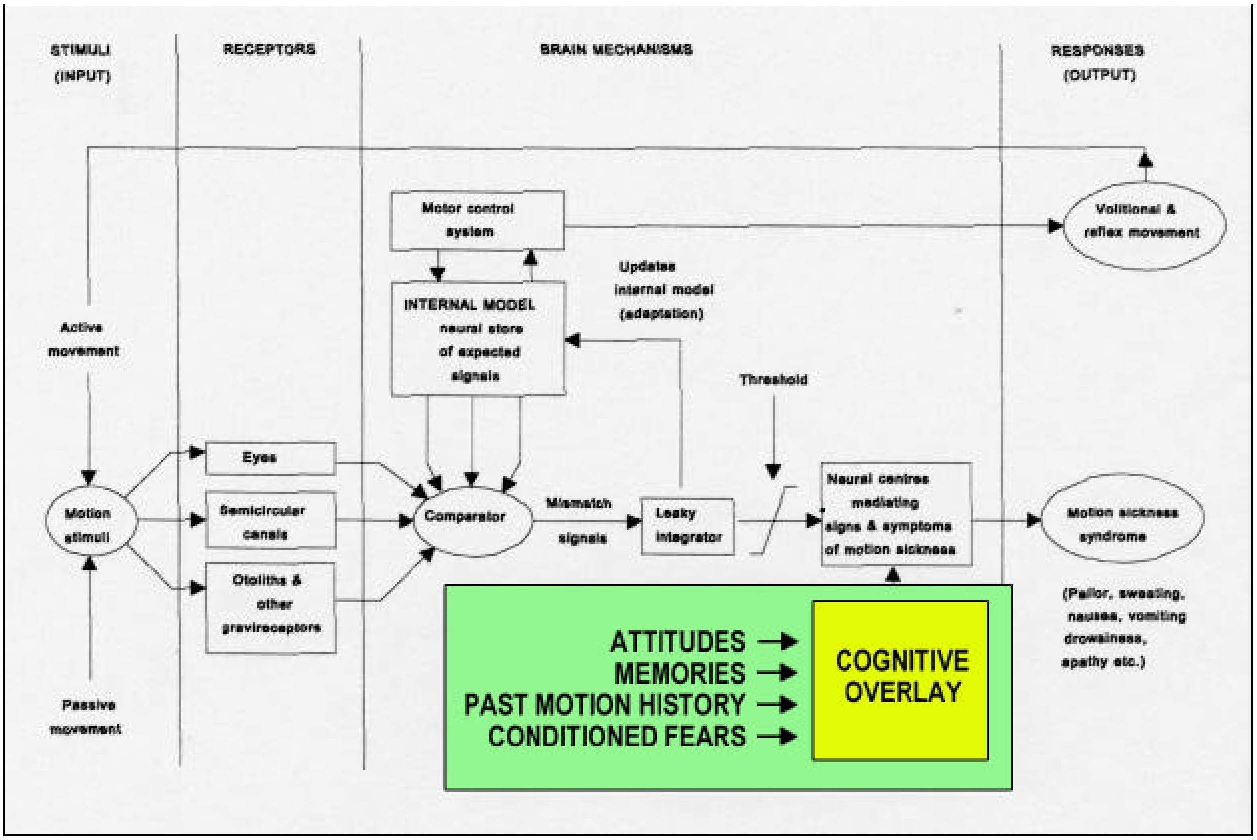

Figure 2. A Schematic of Dobie and May's Psychophysiological Model of the Etiology of Motion Sickness

Characteristics of Provocative Motion

In 1986, Lawther and Griffin[30] pointed out that the early laboratory studies of motion sickness showed that in persons seated in the z-axis motion sickness can be produced by vertical motion with a frequency content below about 0.5 Hz. The combined data further suggested that frequencies below about 0.3 Hz, a magnitude of acceleration around 0.5 ms^2 r.m.s will cause vomiting in roughly 10% of unadapted persons over a period of two hours.

Golding et al.[31] theorized that the ability of low frequency linear oscillatory motion to cause motion sickness depends upon the direction of motion with respect to that of gravity, the orientation of the axis of the body in relation to the direction of motion and body posture.

Golding et al. found that horizontal motion provoked nausea twice as often as vertical motion, but found no such difference between upright and supine postures during exposure to vertical motion. They suggested that an upright posture and stimulation through the X-axis both increase the nauseogenicity of low frequency linear oscillation, and that these effects are additive. They further concluded, however, that the direction of motion with respect to the gravity vector is less important.

Alexander et al.[32] reported upon the last of a series of five studies using the "wave machine" at Wesleyan University. In general, they found that the incidence of motion sickness varied with wave energy. The largest wave produced the greatest amount of motion sickness and the smallest wave the least.

These workers then reviewed the results of the fifth study in relation to the four previous studies carried out on the Wesleyan University wave machine. In this overall series of 5 studies, they controlled or varied the four characteristics of the waves, namely, rate of work during period of exposure (energy x frequency of wave), energy per wave, time per wave (cycling rate) and acceleration-level and wave-form. Although they concluded that their investigations of these matters were not complete, they believed that their results were sufficiently useful to warrant tentative conclusions concerning the relationship between wave characteristics and the estimated incidence of motion sickness. These workers turned their attention both to the capacity of a single wave to produce motion sickness and the total number of waves required to do so.

In the first, third and fifth study in the Wesleyan series, the time per wave (cycling rate) varied, whereas it was constant in the second and fourth studies. They observed that both a "certain intermediate wave-duration and rate of work yielded maximum sickness". On the basis that they believed that the rate of motion sickness accumulated with each wave and decreased with work rate, they concluded that wave duration was the significant variable and that an optimum duration existed for the prescribed conditions.

In the first, second and fifth study, the acceleration level was constant, but varied in the third and fourth in the series. The first study demonstrated wide variations in the incidence of motion sickness during constant acceleration and this study additionally showed variations in sickness rates with a reasonably constant work rate (wave energy x wave frequency). In the third study, it was found that the sickness rates resulting from slow waves with low accelerations were greater than those produced by slow waves with high accelerations, as in the first study. On that basis, they concluded that acceleration is a significant factor. This was confirmed in the fourth study.

In the first, third and fourth studies, energy per wave was constant, whereas it varied in the second and current study. The incidence of motion sickness was reduced when the energy per wave and rate of work were reduced. In this study, the acceleration was constant, rate of work roughly constant and the energy per wave and wave-duration varied. This showed that the energy per wave is a significant factor in producing motion sickness. It was found to decrease even though the rate of energy was roughly constant. Rate of work varied in the first three experiments, but not in the last two. In the fifth experiment, motion sickness varied despite a roughly constant rate of work. They decided that the rate of work alone was not a significant variable.

In general, therefore, Alexander et al. concluded that the incidence of motion sickness depended upon wave duration, acceleration level, wave form and energy per wave and their inter-relationship.

A series of studies by O'Hanlon and McCauley,[13] McCauley et al.[14] and Guignard and McCauley[33] using the ONR/HFR three-axis motion generator produced a diagrammatic model for the frequency and magnitude dependence of motion sickness for vertical z-axis sinusoidal motion in the Z axis. (Figure 3). These workers showed that the most nauseogenic frequency range was from 0.17 to 0.33 Hz. These results are discussed further in relation to the paper by O'Hanlon and McCauley, which is reviewed next. Interestingly, the addition of pitch and/or roll to the basic vertical sinusoidal motion produced no apparent difference in the severity of motion sickness. There has not been very much systematic investigation of the effects of oscillatory motion in other axes.

O'Hanlon and McCauley pointed out that, for a long time, periodic vertical motion had been accepted as the main cause of seasickness but emphasized that, even so, the characteristics of this form of provocative motion were not well defined. They tested 280 subjects on the ONR/HFR motion simulator using 14 experimental conditions in randomly selected groups of 20 subjects. Each of the test conditions consisted of a combination of particular frequency and acceleration levels. Although the duration of exposure was set at two hours, the test was terminated if a subject vomited.

These workers reported a consistent increase in the incidence of motion sickness with acceleration, at every frequency level. Based on their data O'Hanlon and McCauley derived a relationship between the incidence of motion sickness, in terms of the percentage of emesis over a two hour period, and "wave frequency and average acceleration imparted during each half-wave cycle for vertical sinusoidal motion."

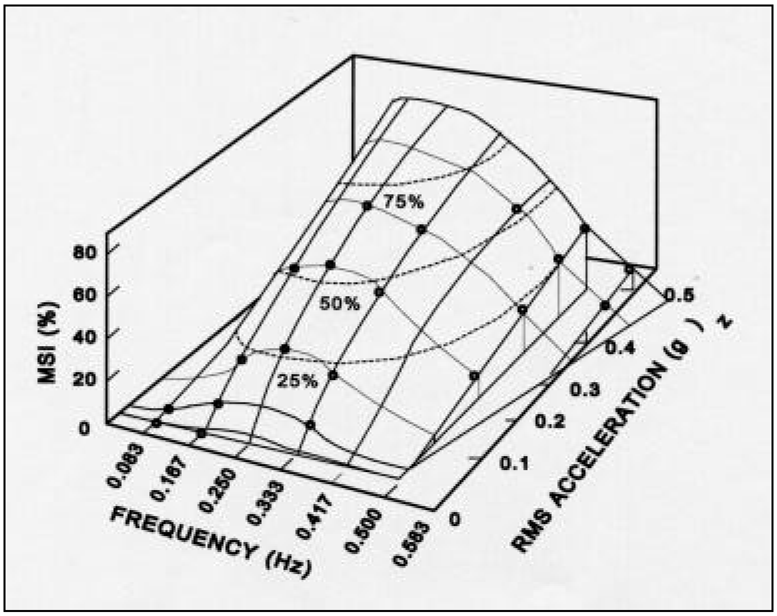

Figure 3. MSI% based on frequency and rms acceleration

They were of the opinion that this model was of practical use, even in this elementary form. For example, it showed that "even moderate accelerations at frequencies near 0.2 Hz should be avoided as these produce the highest incidence of motion sickness." The model also showed that higher accelerations at higher frequencies (e.g., 0.5-1.0 Hz) were less provocative in terms of producing motion sickness. For these reasons, O'Hanlon and McCauley emphasized the importance of avoiding any "engineering strategy to 'smooth out' a ride" if reducing the high-frequency motion (over 0.5 Hz) meant increasing the energy at lower levels of acceleration that are associated with motion sickness. They noted that Kennedy et al.[34] had already offered similar advice in the following manner. They described what they called a "relatively benign range" of frequencies between those which cause motion sickness (below 0.5 Hz) and those higher frequencies which are similar to the resonance frequencies of the human body, which lie between 4.0 and 8.0 Hz. They suggested that engineers should make every effort to design vehicles so that most of the total energy being transmitted to the occupants lies within that frequency range known to be much less provocative.

McCauley et al. later performed an experiment to investigate the effects on the incidence of motion sickness of adding pitch or roll accelerations to a constant vertical motion. The most significant result obtained in this phase of the study was that the addition of pitch or roll did not consistently increase the incidence of motion sickness when compared with the heave only control condition. These workers concluded that this supported the notion that the vertical component represented the main etiological causative factor in producing motion sickness. At the same time, they suggested that this observation created doubt on the suggestion by Miller and Graybiel[35] and Reason and Brand[3] that motion sickness was induced by slight head movements during vertical oscillation. The second phase of this study was designed to investigate the question of habituation resulting from repeated exposure to vertical oscillation, by examining differences in acceleration and duration of exposure.

Overall, these three experiments seemed to indicate that the rate of habituation to provocative motion generally decreased over the 5 day period. The greatest decrease in the incidence of sickness occurred on the second day and habituation was acquired at a slower rate during the remaining three days. Comparing the results of the first two experiments in this series in which the motion profiles differed only in terms of acceleration, greater habituation appeared to be acquired in the condition of greater severity of motion. These workers likened this response to vertical motion of differing severity to effect on habituation of head movements during rotation. They pointed out that Reason and Brand[3] had cited evidence that the development of habituation was expedited by voluntary head movements during bodily rotation. The results of experiments 2 and 3 were then compared. In these two situations only the exposure times and sample sizes differed. In the third experiment the effects of adaptation achieved by means of 1 hour motion exposures each day for 5 days were compared with the results obtained in the previous experiment where each exposure lasted 2 hours. The motion profiles in both of these experiments were the same, namely, 0.25 Hz and 0.33 rms g. It was found that the initial incidence of motion sickness for the two groups was similar, but by the third day, the group receiving 2 hour exposures demonstrated greater habituation. Similarly, the group receiving longer exposures showed greater retention of their habituation. Due to the small sample sizes, any possible gender difference could not be demonstrated significantly. These preliminary results showed that five 2 hour sessions of relatively severe motion provided greater habituation and was better retained than either 1 hour sessions with the same motion or 2 hour exposures with motion of lesser severity. In their final study, the original database was extended to include the incidence of motion sickness associated with vertical oscillation at frequencies between 0.5 and 0.7 Hz, using 101 male students. They used the following 4 conditions: 0.50 Hz, 0.55 rms g; 0.60 Hz, 0.55 rms g; 0.60 Hz, 0.44 rms g; 0.70 Hz, 0.55 rms g. Eight subjects were randomly exposed to a different motion condition each day and the study continued until at least 20 subjects had experienced each condition. The results indicated that the original O'Hanlon and McCauley model based on data up to 0.5 Hz reasonably predicted the incidence of motion sickness up to a frequency of 0.7 Hz, bearing in mind the size of the sample population. They concluded that only high accelerations, greater than 0.55 rms g, would likely produce motion sickness at frequencies above 0.7 Hz and these might well produce other undesirable effects, such as bodily injury in the case of unrestrained persons.

Morton et al.[36] noted that relatively minor changes in the types of motion seemed to alter the incidence of motion sickness. In particular, they found that the pitching motion alone produced as much motion sickness as the combination of pitch and roll. Wertheim et al.[37] carried out a study in their ship motion simulator at TNO in the Netherlands to evaluate the concept, proposed by O'Hanlon and McCauley and McCauley et al., that motion sickness is primarily the result of heave motion and that the pitch and roll components are not significant in the etiology of this malady. They exposed subjects in the simulator to pitch and/or roll both with and without the addition of the heave component. They found that roll and pitch alone seemed to provoke motion sickness and when a relatively small heave component was added to that combination it provoked a marked motion sickness response. As they pointed out, that relatively small amount of heave alone does not produce a motion sickness response. They concluded that heave, pitch and roll should not be seen as merely additive in their contributions to motion sickness and should be considered more in a non-linear fashion.

Table 5. The predicted incidence of seasickness related to the displacement weight of ships

Displacement Weight of Ships (tons)	Predicted Incidence of Seasickness (%)
200	67
1,000	62
3,000	55
5,000	50
10,000	41
15,000	35
20,000	29
30,000	22

During at-sea studies, Pethybridge[38] used the information from the 1,746 respondents in his study of the incidence of seasickness on Royal Navy ships to investigate the incidence of seasickness on vessels on which these crew members had previously served. He used these data to estimate the incidence of seasickness on individual ships and classes of ships other than the 14 vessels involved in his current study. He found that there was a relatively low incidence on large ships, such as aircraft and ASW/Commando carriers, when compared to small vessels such as offshore patrol vessels and minehunters/minesweepers. He concluded that the incidence of seasickness is "linearly related to the square root of the ship's weight or beam". On that basis, he predicted the percentage incidence of seasickness among crewmembers according to the displacement weight of various ship (Table 5). He also noted that those who suffered frequently from seasickness considered that rolling, pitching, yawing, heaving, slamming and vibrating were all highly conductive to this malady, whereas those who suffered infrequently listed pitching and rolling as the most provocative movements.

Lawther and Griffen[30] then reported on their own motion sickness questionnaire studies, which were carried out during a number of voyages on one particular ship. This was a car ferry which operated across the English Channel during the daytime. The weather and sea conditions at the time varied from relatively calm (wind force 4, sea state 2, swell state 2) to very rough (wind force 9, sea state 7, swell state 8). During these channel crossings they recorded both the measurements of the motion of the ship and the resulting seasickness recorded by the passengers who took part in this questionnaire study.

These data were obtained from a total of 4,915 passengers, involving 17 different voyages lasting up to 6 hours in duration. Vertical motion was recorded up to 1.0 ms^{-2} r.m.s. and the incidence of emesis was close to 40%. These researchers reported that both the subjects' magnitude estimate of motion sickness and the incidence of vomiting were well correlated with the root mean square of the vertical z-axis acceleration. They also noted that the duration of exposure to the provocative motion affected the incidence and severity of seasickness. This suggested to them that a combined measure of acceleration(a) and time(t) should be used to quantify the "dose" of acceleration, and found that the relation at^3 gave the best correlation with severity of seasickness. They cautioned, however, that this was a tentative conclusion at this early stage in their investigation.

Lawther and Griffin[39] continued their survey by reviewing motion sickness questionnaires from 20,029 passengers during 114 voyages on nine different passenger ferries around the British Isles. The duration of these various voyages ranged from one-half to six hours, and again the sea states varied from calm to very rough. Using the same methodology as in their previous study, they recorded the incidence of seasickness and other appropriate personal data from the passengers. In addition, they obtained recordings of all six axes of motion of each vessel. The subsequent analyses of these data allowed them to relate the differences in the incidence of seasickness to the variations in ship motion between each voyage and individual ships. With this information, they developed a subjective illness rating scale and used it in parallel with the recorded incidence of vomiting.

Their raw data included ship and sea conditions that provided different motion characteristics. Although they found a degree of correlation between the magnitudes of motion in some axes, sufficient variation remained to show that the incidence of motion sickness correlated best with the magnitude of vertical oscillation.

Lawther and Griffin then compared their data from three separate studies, and found that there was very good agreement in terms of motion sickness induced by vertical oscillation. They found that the effects of the main motion variables also produced simple mathematical approximations which could then be combined to form general predictors. They concluded that if vertical oscillation is great enough to cause seasickness, the additional motion in other axes can be neglected. This supports the observation of O'Hanlon and McCauley[13] that periodic vertical motion is the principal factor in the etiology of seasickness.

They noted that, over their large data set, the effect of the root mean square of the magnitude of acceleration on the incidence of seasickness has an approximate linear relationship. They then used this relationship to create a "normalized sickness index" and determined the effect of the frequency of oscillation. They showed that the greatest sensitivity to acceleration lay in the region of 0.1-0.25 Hz, and that the steep decline at higher frequencies can be described by straight line approximations. These, they point out, can be "used to produce a frequency weighting".

Lawther and Griffin then addressed the question of the duration of the stimulus using the square root of the duration to define a cumulative measure of the "dose" of motion. They treated seasickness as a cumulative variable only, since as they pointed out, it is not likely that the duration of exposure will be sufficiently long for adaptation and recovery to occur. On the other hand, if longer durations were being considered, it would be necessary to include the effects of adaptation before making predictions of the likely incidence of seasickness.

1b. Prevention of Motion Sickness

The prevention of motion sickness is considered here under a number of headings: general measures, the mitigation of specific precipitating factors, factors influencing habituation to motion.

General Measures

During their early motion experiences many people suffer from motion sickness or worry about the possibility of such an occurrence. In this frame of mind they identify a whole variety of situations and apparent trigger mechanisms as causative factors of their malady.[11] Dobie's early clinical observations[9] showed that arousal is a very significant factor in the causation of motion sickness. It may be due to exposure to a form of provocative motion not experienced before, or occur in a person who is exposed to disturbing motion stimuli before growing accustomed to them. Among inexperienced sailors or trainee aviators, anxiety may be due to fear of failing to perform up to the standard that particular person wishes to achieve. It is not due to fear of some outside threat or agency.

A person's general state of health may also be significant. For example, the prodromal symptoms of some infections include nausea, and if this occurs in a motion environment, it may lead to the incorrect assumption that the nausea was caused by that motion. This is more likely to be associated with isolated instances of motion sickness. Individuals who are prone to motion sickness should avoid bulky, greasy meals, particularly if there is little time to digest them before a trip begins. Feelings of nausea associated with food may predispose someone to an attack of sickness unrelated to the vehicular motion. On the other hand, the frequent intake of light snacks can be helpful to some people.

The design characteristics of particular vehicles can influence the response to motion in terms of their frequency and intensity and therefore the degree and character of the provocative stimulation experienced by the crew and passengers.[14] This basic problem can be further influenced by the amount of head movement made by an occupant, since head movements in a changing force field increase the intensity of conflicting vestibular signals. The design of seats and seat harnesses can also play a significant part in reducing active head movements, as can a view of the outside world.

Many individuals are susceptible to foul odors and these may produce nausea even in the absence of significant vestibular stimuli. Similarly, the sight of another person vomiting can be disturbing and produce the same response in the observer. Thus good ventilation in the passenger or crew compartment, together with the discreet management of indisposed individuals, can improve the overall situation.

The Mitigation of Specific Precipitating Factors

Passengers known to be susceptible to airsickness or who show signs of the malady should be located in the most stable part of the vehicle. In the case of ships this will be close to the midline near the center of rotation of the vessel. In aircraft, this is usually a forward position or one located on the line of the wings.

In the case of early experiences at sea, inexperienced passengers should not be invited for a trip when the water is particularly rough, since they will not have the opportunity to get their “sea-legs” before feeling ill. In the case of inexperienced professional crew-members who go to sea in very rough weather, supervisors should keep them as busy as possible in order to keep their minds off their stomachs. They should also be encouraged to eat light meals often.

An individual who is prone to motion sickness should maintain visual orientation by fixating on the horizon or visible land. This question concerning the protection afforded by seeing the horizon is still not fully proven and further research is required. Strong reliable visual cues help to suppress conflicting cues from other sensory modalities. Conversely, susceptible passengers below decks are better off keeping their eyes closed wherever practicable when there is a likelihood of becoming seasick. If possible, they should keep their minds busy or indulge in active conversation. However, reading commonly makes matters worse. Head movements should be kept to the minimum for the reasons already described.

Factors Influencing Habituation to Motion

For most people, repeated or continued exposure to motion over a few days reduces their susceptibility to motion sickness. A state of habituation builds up in response to repeated vestibular stimulation.[40,41] and then decays if exposure to provocative motion is not continued over a period of time, varying from a few days to some six to ten weeks. Supervisors should bear this in mind when scheduling inexperienced crew members.

Treatment of Motion Sickness

We shall consider two forms of treatment of motion sickness: medications and desensitization. The pharmacological approach is very popular, particularly with passengers. However, the side effects of anti-motion sickness drugs generally mean that their use is not suitable for those who are performing skilled or potentially dangerous tasks. The pharmacological approach will only be dealt with briefly.

The Use of Anti-Motion Sickness Drugs

The medication of choice should not have any side effects that are detrimental to an individual's ability to work safely and efficiently. This also requires knowledge of variations in individual responses to the selected standard dosage of that particular drug. In many ways this is much more of a problem than merely finding drugs that exhibit protective effects.

In the context of protecting military professionals both in the air and at sea, the physician must balance the effectiveness of a particular compound and its side effects against the needs of the individual and the tasks the person must perform. For this reason it is essential that usage is strictly controlled by the physician in charge. It is a medical responsibility to ensure that the patient does not exhibit personal idiosyncrasies to the particular drug and that he or she is fully aware of the likelihood and nature of the unwanted effects. We will consider briefly the pros and cons of some commonly-used medications:

Scopolamine (Hyoscine hydrobromide). Scopolamine is probably the single most effective anti-motion sickness drug. The adult oral dose of 0.3 to 0.6 mg is readily absorbed, reaches peak effectiveness after 30-60 minutes, and lasts about four hours. Because long motion exposures require repeated doses, oral scopolamine is best suited for short exposures to provocative motion.[42] An oral dose of 0.6 mg of scopolamine produces side effects consisting of dryness of the mouth, dizziness, light headedness, and drowsiness. A reduction in pursuit performance scores has been reported.[43] Scopolamine has also been shown to impair vigilance and short-term memory.[44] Golding, Strong, and Pethybridge[45] reported that scopolamine (1.2 mg) significantly impaired performance on a variety of mental and motor tasks, altered focal length, lowered heart rate, and produced dry mouth, headache, and dizziness. The effectiveness of scopolamine can be increased by combining it with amphetamine, but, as will be seen later, this is achieved at a price.

Promethazine (Phenerganâ). Promethazine, an antihistamine, is the only phenothiazine proven effective against motion sickness. An oral dose of 25 mg of promethazine is only slightly less effective than 0.6 mg of scopolamine. Its onset of effectiveness begins after some 2 hours and its duration of effectiveness has been quoted as low as 6 hours[46] and as long as 18 hours.[42] Marked sedation and dryness of the mouth are associated with this drug, however. In a retrospective analysis of 94 first flight crewmembers, Jennings et al.[47] reported that intramuscular promethazine had decreased the symptoms of space motion sickness.

Dexamphetamine (Dexedrine â). Dexamphetamine has been shown to protect against motion sickness when used alone and also to act synergistically when combined with scopolamine or promethazine.[46] These drug mixtures in various doses have been shown to be the most effective protection against motion sickness, with better tolerance of head movements shown in laboratory studies of the scopolamine/dexamphetamine mixtures. Dexamphetamine also reduces the sleepiness and performance decrement produced by scopolamine. That is not the end of the story, however. Dexamphetamine is a controlled drug because of its habituating properties and therefore its routine use cannot be justified because of the possibility of addiction. In this context it would be advisable to replace dexamphetamine with ephedrine. That combination would be less effective, but was still better in laboratory studies than scopolamine or promethazine alone. Ephedrine has the advantage of not being a controlled substance, but some undesirable side effects occur.

This review does not purport to be a comprehensive evaluation of drug therapy for the prevention of motion sickness. Rather, it sets out to explore briefly the shortcomings of this approach particularly in terms of the skilled operator (rather than the passenger). Undoubtedly there is a place for anti-motion sickness medication, but this is not the only effective approach. Perhaps the best solution to the problem of motion sickness lies in finding the best protection for a given set of individuals based on what they will be doing when the need arises.

The pharmacological approach to the treatment of motion sickness introduces many problems. The drug actions are variable both in terms of individual responses and the effects of the operational situation on these responses. Some of the potential side effects are not acceptable when the individual is in control of sophisticated equipment or complex operational command and control situations. Finally, it should be remembered that current information suggests that medications are likely to retard adaptation.

The Use of Non-Pharmacological Therapy

Some form of desensitization as a means of preventing or treating motion sickness has much to offer individuals regularly exposed to provocative motion environments. In the military situation, the vast majority of individuals exposed to provocative motion fall into this category; furthermore, they regularly experience these stimuli while carrying out skilled or potentially hazardous tasks. It is this group that can best benefit from non-pharmacological procedures.

A number of different forms of therapy have been developed in various centers around the world for the treatment of motion sickness without recourse to medications. These different approaches to desensitization will be reviewed briefly and compared with Dobie's cognitive-behavioral therapy, both in terms of methodology and effectiveness.

Biofeedback Training. Jones et al.[48] reported the first use of biofeedback instrumentation and training techniques to treat subjects with intractable airsickness. In particular they stated that it was the first time that relaxation techniques had been taught in a challenging and dynamic environment, as distinct from the low-stimulus situation more typical of biofeedback training. Only candidates who were considered well motivated were accepted into the program.

Autogenic-Feedback Training. NASA has used autogenic-feedback training (AFT) to treat motion and space motion sickness. Using operant conditioning to train subjects to control autonomic responses is often called biofeedback; autogenic therapy uses cognitive imagery to control previously involuntary responses. AFT is a combination of both biofeedback and autogenic therapy. It is thought to be considerably more effective than either of these two techniques alone.[49]

USAF Behavioral Airsickness Management Program (BAM). The United States Air Force Behavioral Airsickness Management Program for student pilots aimed to provide immediate treatment close to the undergraduate pilot training site with an expectancy of prompt return of students to flying duties.[50] This approach included behavioral and cognitive modification techniques to reduce airsickness so as not to interfere with safe control of the aircraft.

Canadian Forces Airsickness Rehabilitation Program. The Canadian Forces rehabilitation program began in 1981 with the installation of ground-based desensitization equipment. Although different from the already described RAF and USAF programs, it contains elements common to both.[51]

Cognitive-Behavioral Therapy. This program was started by Dobie in the early 1960's to deal with trainee flight crew who were suffering from severe, and in many cases apparently intractable, airsickness.[11] He decided to investigate the possibility of treating such individuals so that they could return to flight training successfully and eventually become useful, productive operational flight crew. This aim was achieved in a high proportion of cases, and it became apparent that those who did recover finished above the average in training and subsequently as operational aviators in their squadrons. (Table 6). Since then, this form of therapy has been used successfully to treat seasickness and carsickness.

Table 6. FLIGHT TRAINEES GROUNDED DUE TO INTRACTABLE AIRSICKNESS
Results of Cognitive-Behavioral Training in the Royal Air Force prior to 1972
(86% success rate)

Class	Total	Pass	Fail	
			Not Airsick	Airsick
Student Aircrew	44	34	4 (1)	6 (2)
Qualified Aircrew	6	4 (5)	1 (3)	1 (4)
All	50	38	5	7

(1) 3 failed because of poor airwork and 1 left the Service for family reasons. None of these suffered from airsickness.
(2) 2 admitted that they had begun to dislike flying prior to being exposed to any violent aerobatic maneuvers or suffering from any symptoms of airsickness.
(3) Failed because of poor airwork - no signs or symptoms of airsickness.
(4) Marked phobic element in this case.
(5) 2 of these cases showed evidence of phobia related to a particular aircraft type.

This form of therapy, now known as Cognitive-Behavioral Therapy, is based on a combination of vestibular training as a means of desensitization, together with confidence-building counseling. It differs from these other methods of desensitization training in a number of ways. There are no preselection of candidates, no physiological measures as required for biofeedback and is the only program that includes a cognitive component to reduce anticipatory arousal. A person suffering from severe incapacitating motion sickness inevitably shows some degree of anxiety or loss of confidence by the time he or she is referred for a second opinion. This psychological overlay seems inevitable because the subject is quite likely to develop anticipatory anxiety in association with the provocative motion stimuli that have previously led to motion sickness. In addition, professionals who experience motion sickness feel that their careers are in jeopardy, and this adds to their anxiety. This suggests that vestibular training alone is not enough; the anxiety overlay also requires attention.

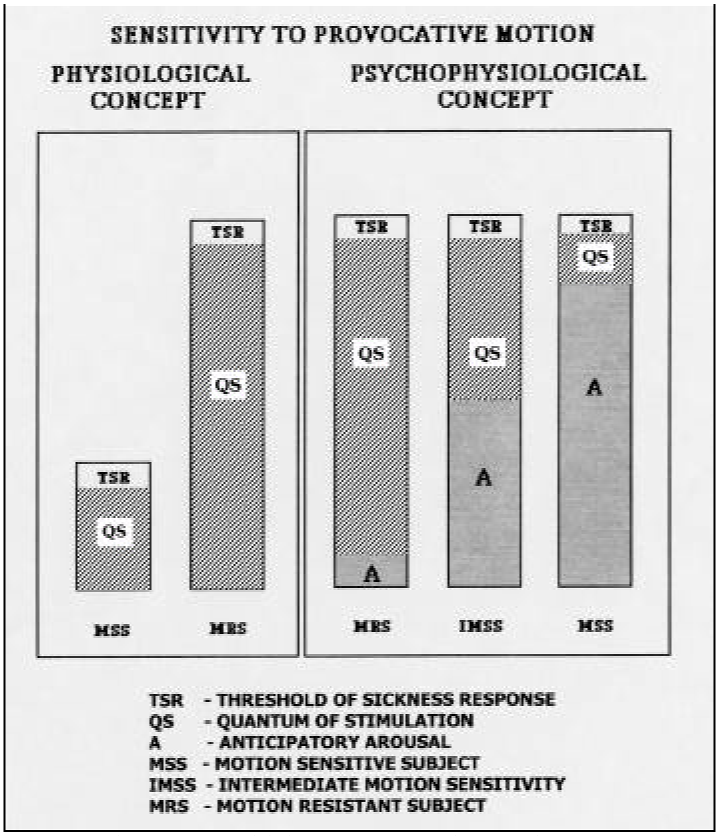

Figure 4. Sensitivity To Provocative Motion

This psychophysiological concept is shown in Figure 4. A person who is apparently susceptible to motion sickness is, in reality, not very different from an apparently resistant person, other than in his or her level of anticipatory arousal. This arousal prevents a person experiencing provocative motion long enough to allow adaptation to occur. The rationale of Cognitive-Behavioral Therapy, therefore, is based on the principle of relieving the patient's state of arousal while building acclimatization to vestibular stimulation on a rotating/tilting chair. The passive head movements involved produce cross-coupled or Coriolis stimulation of the semicircular canals, resulting in a sensation that is frequently bizarre and disorienting. The stimuli are carefully controlled so that subjects never experience more than the early symptoms of motion sickness, and no one ever gets even close to emesis. This approach is critical to the development of confidence. It addresses the main problems in parallel, namely lack of acclimatization to motion and a heightened anxiety state. A candidate's improved performance on the rotating/tilting table, shown by an ability to withstand increasing amounts of vestibular stimulation over time, helps to increase confidence and lessen anxiety. Although this form of therapy was designed to treat airsickness, the principles involved are appropriate to any form of motion sickness and have already been used equally successfully to manage other forms of provocative motion.

Results of Therapy. The overall results of this program showed that all individuals improved their tolerance to stimulation on the motion device and 86% of them were successfully returned to full, unrestricted flying and none had recurring problems with motion sickness. (Table 7). A long-term follow-up, which took place after the candidates had been flying on operational squadrons for a number of years confirmed the successful retention of all of our ex-patients who had completed training. In addition, this group of individuals was rated above the average. It also confirmed that they were no longer hampered by motion sickness.

Table 7
Results of Cognitive-Behavioral Training in the Royal Air Force prior to 1972

Class	Total	Pass	Fail	
			Not Airsick	Airsick
Student Aircrew	44	34	4(1)	6(2)
Qualified Aircrew	6	4(5)	1(3)	1(4)
All	50	38	5	7

(1) 3 failed because of poor airwork and 1 left the Service for family reasons. None of these suffered from airsickness.
(2) 2 admitted that they had begun to dislike flying prior to being exposed to any violent aerobatic maneuvers or suffering from any symptoms of airsickness.
(3) Failed because of poor airwork - no signs or symptoms of airsickness.
(4) Marked phobic element in this case.
(5) 2 of these cases showed evidence of phobia related to a particular aircraft type.

Dobie has also equally successfully treated sailors who were referred with severe intractable seasickness. They were given the same type of cognitive-behavioral training as the flight trainees and successfully returned to an unrestricted seagoing career.

Review of Military Desensitization Programs

The published results obtained from various military programs have shown that Dobie's cognitive-behavioral program carries the highest success rate. It is evident that all of the programs are effective. However, apparently none of these newer programs has improved upon the success rate of the original program, despite the additional efforts and extra costs involved. This calls into question the value of complicating the relative simplicity of the original cognitive-behavioral approach, quite apart from the significant cost increase involved in so doing.

Recommendations

Given the multitude of factors contributing to the incidence of motion sickness in a variety of settings, it is logical to assume that this malady maybe of concern for the JCC(X) platform. It is of importance, therefore, to evaluate the motion profiles produced in these vessels at various locations aboard ship in various sea states. Initial estimates of these motion profiles should be obtained with at sea recordings of ship motion. These recordings could then be used to produce laboratory simulations of motion wherein the incidence of motion sickness might be evaluated for this class of vessel. Obvious factors to consider in such evaluations include:

A) Gender differences in MS susceptibility;
B) The degree and time-course of adaptation;
C) The effectiveness of pharmaceutical intervention and in particular, its effect on adaptation;
D) The effectiveness of psychological training; and
E) Various combinations of pharmaceutical and psychological intervention.

Regarding paragraph (C) above, concerning the question of the effect of medications on the ability to adapt to provocative motion, this could be of paramount importance to the prevention of seasickness on the JCC(X). In the earlier reference to Walter's study and to Table 4 in particular, he showed that it took some 4 or 5 days for the crewmembers to get their sea legs in moderately severe weather or worse. It would be highly advantageous to identify a medication that could protect individuals during these early days in heavy seas and at the same time did not prevent them from adapting to the motion in the meantime. Urgent studies are needed to address this critical issue. All of these studies would provide important information about the likelihood of motion effects such as motion sickness and the sopite syndrome (described in section 2), with recommendations concerning how these problems might be counteracted in various sea states.

Chapter 1 Summary Table

Causes of Motion Sickness	Description and/or experimental results (when available)
Neural mismatch hypothesis	The result of mixed signals at the comparator in the brain. Anticipitory motion differs from actual expected motion.
Direction of motion	Horizontal motion provoked nausea twice as often as vertical motion.
Wave type	Inconclusive
Work rate	Not significant variable
Frequency and acceleration of motion	Significant variables. Approximately .2 Hz was determined to be the frequency where motion sickness was most prevalent. *Please refer to Figure 3.*
Pitch and roll	Not significant variables by themselves.
Heave	When heave is compounded with pitch and roll there is a significant increae in motion sickness.
Vertical oscillation	If vertical oscillation is great enough to cause sea-sickness, additional motions on different axes can be neglected.
Head motion	Extra head movements significantly contribute to motion sickness.
Addressable Factors	**Measures and/or Treatments to be taken**
Minimize ship motions near .2 Hz.	Pursue damping techniques that can minimize exposure at or near this critical frequency. *Please refer to Figure 3.*
Habituation	It was found that significant resistance to motion-sickness occurs after 5 days.
Ship weight	Motion sickness is reduced in heavier ships. Incidence of sea sickness is linearly related to the square root of ship's weight. *Please refer to Table 5.*
Diet	Foods that do not digest easily such as bulky, greasy meals contribute to sea-sickness.
Head movement	Specially designed seats and/or beds to minimize head motions will help reduce motion-sickness.
Ventillation	Offensive odors such as vomit must be minimized to reduce motion sickness.

Medications				
	Name:	Dose:	Pros:	Cons:
	Scopolamine	.3-.6mg/4 hrs.	Most effective single drug.	Dry mouth, dizziness, light headedness, drowsiness, impaired vigilence.
	Promethazine	25mg/6-18 hrs.	Less effective than Scopolamine	Sedation, dry mouth.
	Dexemphetamine	N/A, usually combined in various concentrations with Scopolamine or Promethazine	More effective and less side-effects than any single medication.	Controlled substance that can lead to addiction.

Desensitization therapies			
	Name:	Involvement:	Advantages:
	Biofeedback training	N/A	Not enough information
	Autogenic feedback	Cognitive imagery to control previously involuntary responses. Combination of both biofeedback and autogenic therapy	More effective than biofeedback training
	USAF behavioral airsickness management program (BAM)	N/A	N/A
	Canadian Forces airsickness rehabilitation program	Shares elements common to USAF and RAF programs.	N/A
	Cognitive behavioral therapy	Vestibular training and confidence building counseling. Only program to reduce anticipitory arousal (solves brain's comparator problem).	Most effective treatment. 86% success rate. Decrease in anticipitory arousal that leads to more resistance to provocative motion and motion sickness. *Please refer to Table 6, Figure 4 and Table 7*

Chapter 1 Summary Table (Continued)

Chapter 1 Supplemental Tables and Figures

Table 7.2 from NATO STANAG 4154 (Edition 3).[52]

Application	Performance Limitations		
	Motion	**Limit***	**Location**
Recommended Criteria	Motion Sickness Incidence (MSI)	20% of crew @ 4 hrs	Task Location
	Motion Induced Interruption (MII)	1/min	Task Location
	Relative Wind	35 kts	Task Location if on Weather Deck
Default Criteria	Roll	4°	
	Pitch	1.5°	
	Vertical Acceleration	0.2g	Bridge
	Lateral Acceleration	0.1g	Bridge
	Relative Wind	35 kts	Flight deck

*Note: - Roll, pitch and acceleration limits are given in terms of root-mean-square amplitude.
- To achieve US NAVY significant single amplitutes for roll, pitch, vertical and lateral accelerations multiple the limits stated by 2.

Human factors related limiting values for vertical accelerations (Karppinen, 1987) from Table 8 of "Criteria for Seakeeping Performance Prediction", VTT, ESP00, 1987[53]

Vertical Acceleration RMS	Description
0.275g	Simple light work. Most of the attention must be devoted to keeping balance. Tolerable only for short periods on high speed craft. Conolly (1974), Bakenhus (1980).
0.2g	Light manual work to be carried out by people adapted to ship motions. Not tolerable for longer periods. Causes quickly fatigue. Mackay & Shmitke (1978), Applebee & Baitis (1984).
0.15g	Heavy manual work, for instance on fishing vessels and supply ships.
0.1g	Intellectual work by people not so well adapted to ship motions. For instance scientific personnel on ocean research vessels (Hutchison & Laible, 1987). Work of a more demanding nature. Long-term tolerable for the crew according to Payne (1976). The International Standard ISO 2631/3 (1985) for half an hour exposure period for people unused to ship motions (Figure 8).
0.05g	Passengers on a ferry. The International Standard for two hours exposure period for people unused to ship motions. Causes symptoms of motion sickness (vomiting) in approximately 10% of unacclimatized adults. Goto (1983), Lawther & Griffin (1985).
0.02g	Passengers on a cruise liner. Older people. Close to the lower threshold below which vomiting is unlikely to take place. Lawther & Griffin (1985).

SPC limiting values for human effectiveness (Karppinen, 1987) from Table 6 of "Criteria for Seakeeping Performance Prediction", VTT, ESP00, 1987[54]

Root Mean Square Criterion			Description
Vertical Acceleration	**Lateral Acceleration**	**Roll**	
0.20g	0.10g	6.0^0	Light manual work
0.15g	0.07g	4.0^0	Heavy manual work
0.10g	0.05g	3.0^0	Intellectual work
0.05g	0.04g	2.5^0	Transit passengers
0.02g	0.03g	2.0^0	Cruise liner

Figure 98 from ASTM F-1166.[55]

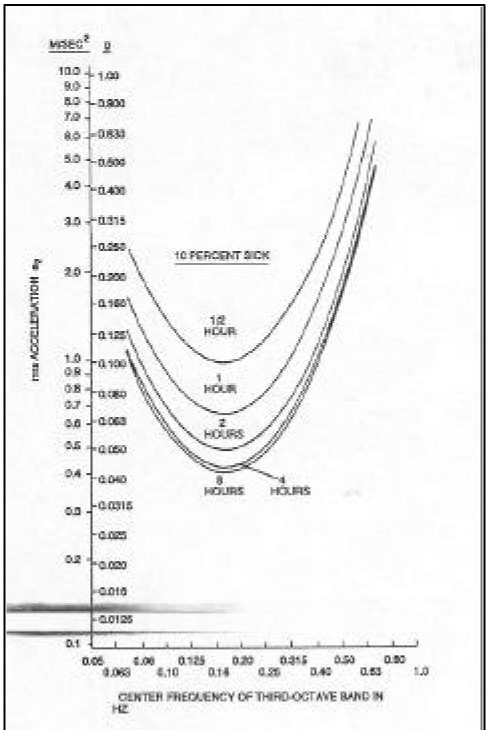

FIG. 98 The 90% Motion Sickness Protection Limits for Human Exposure to Very Low Frequency Vibration

Figure 7 from Colwell Presentation of September 2000.[56]

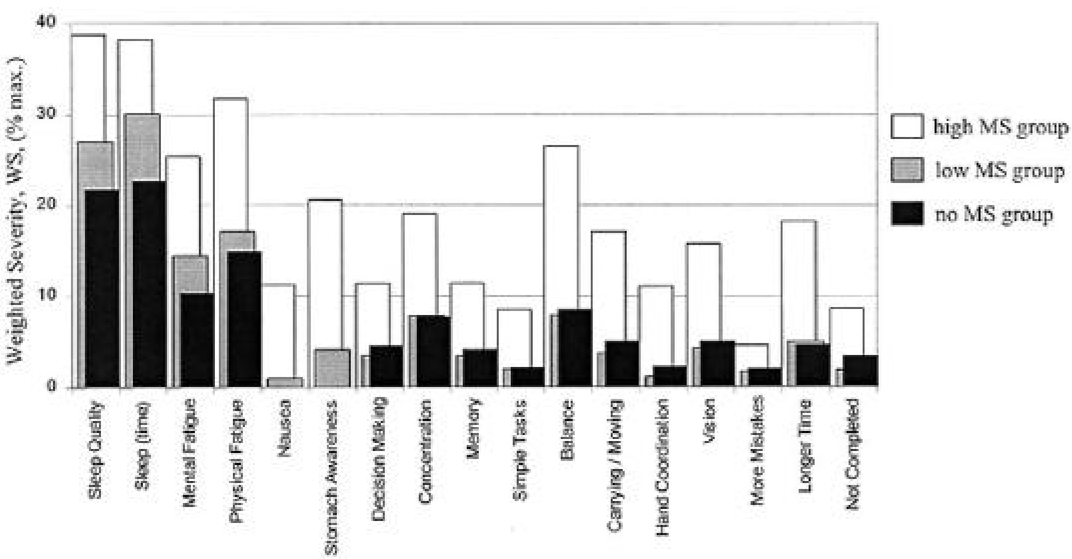

Figure 7: WS averages for Ship D; Subject Groups no MS, low MS and high MS

2. Sopite Syndrome

Executive Summary

Fatigue and drowsiness have been suggested to be frequent side effects of continuous ship motion. These effects can cause severe reductions in vigilance and performance decrements in human operators. It is suggested that the potential for these effects be evaluated through simulations of JCC(X) motion profiles and that putative counter measures be evaluated. Recommendations concerning how this might be accomplished are made.

2. Sopite Syndrome

The sopite syndrome is a subjective response that is characterized by drowsiness and mental depression. Other symptoms include fatigue, difficulty in concentrating and disturbed sleep. Graybiel and Knepton,[57] unlike many of their predecessors in the field of motion sickness, reported that drowsiness, is one of the cardinal symptoms of motion sickness. As long ago as 1912, Byrne stated that " the effects of seasickness on the nervous system create psychic depression so extreme, and a disturbance of cerebral function of such magnitude, that self-control becomes impossible."[58] In 1936, Hill[7] reported that sleep had an important bearing on seasickness, pointing out that drowsiness, apathy and mental lethargy, without actual somnolence, were present.

In 1954, Schwab[22] noted that motion sickness includes a variety of minor symptoms that escalate before actual nausea and vomiting occurs. It is interesting to note that he introduced the first symptom as "rather a subjective one and [it] is described as an uneasy feeling with a certain amount of lack of interest in the task being done". He noted that in such cases "no visible signs are shown by the subject at this point and a great many travelers bothered by motion sickness may pass through this phase alone and never develop further symptoms or complaints because of the termination of their trip." Schwab suggested that these people would not admit to being motion sick even if aware of "this subtle change in their normal habits." He continued to state that " this mild lack of interest in the immediate environment increases steadily and is accompanied by a certain amount of yawning." Could this be an early reference to what we now call the "sopite syndrome"? If so, it still begs the question as to whether it is part of motion sickness or a separate entity of some other origin.

Although Lawson and Mead[59] indicated that this syndrome is little understood, nevertheless they suggested that is a distinct syndrome from either what we know as motion sickness or a state of fatigue. They also considered that it could have particularly profound effects in different transport environments where, for other reasons, sleep disturbances already exist. We already know that sleep disturbances are very common at sea, and this may mask the sopite syndrome, if indeed it is a separate entity. Whether that is the case or not, we do know that sleepiness and fatigue are commonly reported in provocative motion environments. Lawson and Mead stress that the sopite syndrome does not appear to have a different time coarse from the other symptoms of motion sickness, that it commonly appears before nausea, and persists after the nausea has disappeared. In our laboratory, we have noticed significant yawning and apparent sleepiness both before the onset of nausea and after the end of provocative motion. Also, we have reports of nausea during the follow up period after these events took place.

Lawson and Mead raised an important issue, namely that even mild sopite syndrome responses could create a significant problem if they are not readily recognized. Certainly, it has been our experience in this laboratory that general discomfort is a common cause of motion sickness and this may indeed be related to the sopite syndrome if indeed that syndrome is associated more directly with low-grade motion sickness. These workers also have provided a number of anecdotal reports concerning sopite syndrome. These are very interesting because the cover a wide range of situations. In one case, in a low-level navigation sortie in bumpy conditions, an observer noticed that a student passenger in the aircraft had fallen asleep. However, in that situation, it is quite likely that the aircraft motion was sufficiently provocative as to cause conventional motion sickness responses. At the other end of the spectrum, they report individuals being sleepy when driving on long road trips in conditions, which may not be particularly provocative. In another situation, a flight surgeon reported crew members becoming extremely drowsy and suffering mood depression during rough seas. They described tank crews reporting drowsiness during the movement of the vehicle and also subsequently, after the vehicle had stopped for a rest break. A former SkyLab astronaut reported sluggishness and loss of appetite which he attributed to what he called “sub-clinical motion sickness”.

It is clear that this issue requires further investigation in order to identify the cause of the symptoms associated with the sopite syndrome. They may simply be typical symptoms of low grade motion sickness occurring during and or after exposure to provocative motion. They may be associated with environmental factors such as high ambient temperature, isolation or exposure to enclosed spaces. Until these elements are investigated in a controlled fashion, this question of the sopite syndrome being a part of conventional motion sickness or a separate entity remains open to conjecture.

In a recently completed investigation at NBDL, we began to address some of these issues. The study involved the measurement of symptoms during motion provided by a six degree of freedom motion platform driven by representative ship motion profiles. We measured symptomatology when subjects were exposed to simulated motion only, simulated motion with extraneous lights and tones, and simulated motion while (counting) the occurrence of each type of tone or light. Unlike previous experiments, we included a static control condition. We found significant increases in drowsiness, boredom, stomach awareness and fullness of head during the experimental periods relative to pre- and post- experimental periods. However, these increases were no greater during motion that they were during the static exposure. Extraneous stimulation and mental performance reduced these symptoms. This suggests that the sopite syndrome might be associated with physical inactivity and not whole body motion *per se* and it might be offset by mental stimulation and required performance.

Recommendations

Whether the sopite symptom is motion-provoked or inactivity-provoked, it may well serve to compromise cognitive performance and herald more severe aspects of motion sickness. For this reason, it is important to evaluate the incidence of this syndrome under motion and task conditions anticipated with the JCC(X) operation. It would be appropriate, therefore, to include assessments of sopite symptomatology in the evaluative efforts recommended with regard to motion sickness and cognitive functioning (see above). The techniques to be studied with regard to those concerns (pharmaceutical treatment, physiological treatment, and psychological counseling) may also reveal effects which mitigate sopite effects and improve operational performance.

3. Virtual Environments

Executive Summary

Current display technology can cause simulator sickness and disorientation on stationary platforms and it is anticipated that these deleterious effects on operator performance will be exacerbated when these devices are employed on modern vessels at sea. It is important to assess the degree to which users of this new technology will be impacted when they attempt to employ virtual environments on the JCCC(X). Suggestions as to how such problems may be simulated and studied are recommended.

3. Virtual Environments

Virtual environments have the potential for both degrading and improving performance. Some virtual environments may provoke symptoms of motion sickness, usually referred to as simulator sickness. Other researchers have found that the use of virtual environments improved training and information processing. Virtual environments may or may not include a dynamic input such as motion or vibration, and the degree of immersion in the virtual environment may vary significantly. Several studies have documented the interaction of virtual environments with dynamic environments and indeed have documented performance decrements in the presence of virtual environments alone.

Simulator sickness, while similar to motion sickness and space sickness, has distinct features in symptomatology and time course.[60] Past motion sickness history is not a good predictor of simulator sickness susceptibility.[61] Virtual environments with a large field of view, providing extensive stimulation of the peripheral visual system have been found to provoke simulator sickness without dynamic input.[62] Poor resolution, lags in the visual display and sources of sensory conflict have been identified as possible causes for simulator sickness evoked by virtual displays. Effects of virtual environments can be classified as nausea, disorientation and oculomotor effects, which each act through different pathways.[63] Delay between head movement and the movement of the virtual scene results in a neural or sensory mismatch. The effect of the sensory mismatch differs when head movements control the visual scene and when hand movement controls the visual scene, with head movement-driven visual scenes being the most nauseogenic.[64] Prolonged exposure to immersion in virtual reality systems produces symptoms ranging from dizziness to severe nausea.[65] Although simulator sickness can be reduced by motion sickness medications, the aftereffects of simulator sickness do not appear to decay as soon as motion sickness, which may have implications for military performance when simulators are used for mission training or orientation. In additions to the symptoms of simulator sickness (nausea, disorientation and oculomotor effects), proprioceptive aftereffects may linger for as long as 30 minutes afterward. Subjects exposed to virtual reality presented by a head-mounted display had greater inaccuracy in a pointing task with eyes closed than with eyes open. This suggests that the orientation to the virtual world provided inaccurate reference information when compared to the visual reference.[66] While some researchers have suggested the use of an independent visual reference connected to an inertial reference within the virtual environment, this research is not yet conclusive and more study is needed to determine if this technique has merit.[67] Evidence that negative affects of simulators are more postural and physiological than cognitive suggests that virtual environments have excellent potential for training and orientation, once simulator and virtual environment design has resolved the current issues of refresh rate, display lag, and orientation with the inertial frame of reference.[68]

The beneficial aspects of implementing virtual environments should also be recognized. When designed well, virtual environments can have a significant positive impact on information processing and information resource management.[69] Virtual spatial displays can result in 30 percent faster information processing and better retention of the information presented.[70] Simulators with good agreement to the temporal world have been shown to improve performance in pilots.[71] Of these, fixed-base simulators without a dynamic input appear to have lower rates of simulator sickness. Simulators employed on motion platforms may result in an exacerbation of motion sickness problems because of conflicting visual and vestibular inputs.

Recommendations

Virtual displays are becoming an ever-increasing component of environmental monitoring and control, and it is obvious that future vessels will include this technology at numerous levels. Given the potential for debilitating motion and simulator sickness, it is reasonable to devote considerable research and development effort to anticipating the types of virtual simulations to be employed on the JCC(X) vessels and determining how these displays may interact with ship motion to produce debilitating effects. Evaluating performance in virtual scenarios with simulations of JCC(X) motion profiles would highlight potential problem areas and suggest appropriate solutions. It would be very informative to evaluate existing COTS technology using representative motion profiles in anticipation of designing the display technology to be employed on the JCC(X) vessels.

4. Cognitive Effects

Executive Summary

Many of the human tasks which are readily performed with efficiency on land may be compromised by various factors (ship motion, vibration, fatigue, motion sickness, etc.) at sea. It is important, therefore, that a considerable research and development effort be dedicated to an examination of the types of cognitive tasks to be performed on the JCC(X) and the degree to which they might be degraded. Recommendations concerning the implementation of that effort are proffered.

4. Cognitive Effects

With the recent increase in the use of technology, more and more of the staff and crews of ships like the JCC(X) are involve in mental rather than physical work This increased mental workload, particularly against a background of stress, merits careful consideration. The question is where do we start? In 1979, Moray[72] was of the opinion that there was no satisfactory single definition of mental workload. As Kantowitz and Sorkin[73] pointed out, it is many things to many people. In their list they included, information processing and attention; the time available to carry out the task, and stress and arousal. Williges and Wierwille[74] discussed three broad ways to obtain measures of mental workload. First, subjective opinions based on rating scales or interviews. Second, measures of spare mental capacity obtained from information theory[75]. Finally the primary task method, which assumed that as mental workload increased, performance of the primary task was decreased. On the other hand, when discussing the psychophysiological aspects of motion sickness, Birren[76] put forward different evidence. He observed that most individuals who are transiently motion sick could exert themselves to a level of adequate performance when the situation dictates. He referred to this as “peak efficiency”, as distinct from the daily routine which he called “maintenance efficiency”.

Rolfe[77] had already addressed some of these issues when he discussed the abilities of the human operator. He described three significant limitations. First, limited channel capacity, which can cause an operator to become overloaded resulting in a loss of efficiency. Second, at the other end of the spectrum, what he described as “poor monitoring ability” causes a decrement of performance through under-stimulation. Vigilance, or lack of it, causes signals to be missed or response times to be increased. Third, is the existence of human time lags, or operator reaction time. This involves a number of components. There is the *sensing time*, which is a characteristic of the properties of the signal. The *perceiving time*, which is a function of the complexity of the signal and the amount of interpretation required. The *decision time* related to the complexity of the situation and the *response time*, related to the complexity of the response. Christensen and Mills[78] summarized their concept of overall operator performance under four broad headings, three of which related to cognitive performance and the last to physical demands. First, *perceptual processes*, which they described as “searching for and receiving information” and “identifying objects, actions, and events.” Second, *mediational processes*, that included “information processing” and “problem solving and decision making.” Their third category included all *communication processes*. Finally, they described *motor processes* as being either “simple discreet” or “complex/continuous”. This brief summary of the situation still provides a useful framework for addressing cognitive issues today.

Having obtained a feel for the various factors that comprise the cognitive aspects of the effects of ship motion on crew performance, we must now decide how best to measure these features. Tijerina et. al.[79] discussed the merits and demerits of using “Operational Tests and Simulations” or the “Taxonomic Approach and Human Abilities”.

(a) Operational Tests and Simulations:

Tijerina and his colleagues did not recommend this approach for the following reasons:

(i) The equipment and personnel required for certain operational scenarios may exceed the capacity of a ship motion simulator;

(ii) Complex operational scenarios would require trained, experienced operators;

(iii) Realistic trial times for certain scenarios may be too long for laboratory simulation;

(iv) Operational tasks may have a *measure of merit* problem; do results or process evaluate the quality of decision making better?

(v) When operational test performance is degraded it is difficult to identify the reason because of the complexity of the task:

(vi) Operational Tasks may be highly unreliable, as reported by Lane et al.,[80] suggesting that the erratic fluctuations of operational performance make it unreliable to use operational task simulation to predict shipboard operational performance.

(b) Taxonomic Approach and Human Abilities

Tijerina et al. suggested that it is not completely clear what current laboratory tests of cognitive performance are measuring. Nor is it clear how these test results relate to actual operational performance. For these reasons they proposed a taxonomic approach as a means of measuring and predicting human performance. Fleishman and Quaintance[81] have proposed several classes of these taxonomies and of these, the most developed is Fleishman's Human Abilities (HA) Taxonomy.[82] They suggested the following rationale for this experimental approach.

(i) Different mixes and levels of human abilities are required to carry out shipboard tasks. These include selective attention, stamina, memorization and manual dexterity;

(ii) The human abilities concept provides a means of describing different tasks with a common vocabulary;

(iii) The susceptibility of various human abilities to the provocative effects of ship motion may be different;

(iv) This approach allows the effects of ship motion on cognitive performance to be assessed by means of tests that demand abilities similar to those required to carry out tasks on board ships.

They stress that abilities are not equivalent to skills:

> "(A)n ability is a general trait of the individual that has been inferred from certain response consistencies. Both learning and genetic components underlie ability development. In contrast, a *skill* is defined as the level of proficiency on a specific task or group of tasks. The development of a given skill or proficiency on a given task is predicated in part on the possession of relevant basic abilities.
> (Fleishman & Quaintance, 1984, P. 162)."

The successful use of the Abilities Taxonomy lies in the ability to identify the ability, or abilities, necessary to perform a particular task. To that end Fleishman and his colleagues have provided a Manual for Ability Requirement Scales in order to standardize the identification of abilities across raters and task situations.

Cognitive Performance

While the theoretical approach to classifying human performance suggests ways in which we might design experiments to address these issues, a number of empirical experiments have been carried out to date with equivocal results. Some find no adverse influences on cognitive performance during motion, while others observe deleterious effects.

Alexander et. al.[83] reported an investigation of the effects of ship motion on human performance in which the subjects carried out a set of simple psychomotor tasks before and after, but not during, exposure to provocative motion. Some time later, Abrams et. al.[84] carried out a more comprehensive investigation of this matter. In this series a more comprehensive series of cognitive tasks was used while subjects were exposed to five different motion conditions together with a stationary control condition. Malone[85] investigated the effects of simulations of the motions of a *surface effect ship* on crew habitability, using different cognitive tasks over three different motion conditions. The researchers who carried out these three experiments concluded that ship motions had no effect on cognitive performance as measured in these studies. In a different type of experiment in which four aviators were exposed to a rotating environment for 12 days in a slow rotation room at 10 rpm, Graybiel et. al.[86] concluded that there were no adverse effects on cognitive performance.

On the other hand, there have been reports of sea trials that seemed to indicate loss of cognitive performance due to exposure to provocative motion. Wiker et al.[87] carried out a study at sea in which they gathered data on six different measures of cognitive performance from crewmembers on three different vessels. These were 95-foot US Coast Guard White Patrol Boat, a 378-foot US Coast Guard High Endurance Cutter and an 89-foot Navy Small Waterplane Area Twin Hull (SWATH) vessel. Using a within-subject experimental design to compare the difference between a subject's performance during provocative motion at sea with a static condition, they reported significant decrements in performance on five of the six measures. It has been reported by several authors that Sapov and Kuleshov[88] reported significant reductions in performance during ship motion in a study which they carried on crewmembers of surface ships. However, a study of a translation of their original paper is not clear on this matter. In the first month at sea, they reported that a "decrease in mental performance was characterized mainly by larger numbers of mistakes in the memory, attention and mental arithmetic tests and a larger number of errors in the complex sensorimotor reactions. However, the speed of the reactions and efficiency in the [blank] tests were not affected." After a month at sea, job performance improved "because of the increase in operational skill, good morale and psychological hardening of the sailors."

Wilson et al.[89] carried out a study on the Naval Biodynamics Laboratory ship motion simulator using a battery of cognitive performance tests that included Grammatical Reasoning, Short-term Memory, Pattern Matching, Simple Reaction Time and Complex Problem Solving. A complete experimental session lasted about two hours. They used five different heave conditions and five different roll conditions. In terms of heave motion, these workers reported that 4 of the 5 subjects demonstrated significant slowing in cognitive processing, whereas the effects on cognitive processing were reported as equivocal. They concluded that their results did not provide conclusive evidence that heave motion adversely affects the accuracy of cognitive processing. The results with roll motion did not show adverse effects on cognitive processing. In the following year, Pingree et al.[90] measured the performance of psychological tasks on the SES-200 hovercraft during both mild and severe motion conditions at sea. They reported that no significant decrements in cognitive performance were noted on the three computer-based cognitive tasks used in this study. A later experiment was carried out on that simulator to develop and validate objective test procedures for display manning and decision making tasks. Crossland[91] and Conwell Holcombe et al.[92] reviewed these data from 25 US Navy human research volunteers obtained during 90 minute exposures to simulated ship motions representative of a US frigate in sea state 5 and found that purely cognitive skills were not adversely affected.

Wertheim[89] at the TNO Human Factors Research Institute, The Netherlands, reviewed this subject and concluded that ship motion does not adversely affect the performance of cognitive tasks. Wertheim et. al. [93]

also carried out an experiment to study the possibility that simulated ship motions of a small boat, provided by their ship motion simulator, would adversely affect task performance. These results also suggested that cognitive performance is not adversely affected by ship motion. However, as Wertheim[94] reported, “In the long run, drowsiness or motion induced physical fatigue may induce a gradually increasing resistance to carry on with the task. But only when this resistance becomes too high to overcome will task performance deteriorate, and then rather dramatically so.”

Recommendations

Most of the cognitive tasks employed in previous experiments involved relatively short-term exposures or fairly simple cognitive tasks. In addition, the problems addressed were modeled on the performance of experienced sailors carrying out rather low-level tasks involved in ship maintenance and control. The current concerns are for more executive level functioning by individuals who are not necessarily habituated to conditions at sea. In light of these concerns and the equivocal nature of the findings noted above, we would suggest a series of future investigations that address higher level cognitive performance and team interactions that better approximate the tasks to be carried out in the ships under consideration. This would involve the development of realistic operational simulations and the use of subjects with limited sea-going experience. To the degree that decrements in cognitive functioning can be related to motion sickness and the sopite syndrome often associated with motion, the evaluation of various techniques that may provide prevention or treatment of these potential maladies should also be included in these efforts. Thus, the evaluation of cognitive functioning under putative preventive measures such as pharmaceutical treatment, physiological adaptation, psychological counseling and combinations of these potential protective regimens (see recommendations regarding motion effects). In addition, the possibility that artificial horizons might ameliorate motion sickness or disorientation should be considered and systematically investigated.

5. Whole-Body Vibration

Executive Summary

In addition to the low frequency motion provided by ship motion, the human operator is sensitive to high frequency vibrations that are produced by hull slamming, the drive-train and other mechanical equipment aboard sea going vessels. In addition, the effect of blurring caused by COTS computer monitors can produce a significant operational limitation. With appropriate simulations, it is possible to anticipate the degree to which such vibrations will present problems for ship board operations, and potential solutions may be evaluated. Evaluations of contemporary manipulative devices and improvements to equipment-platform interfaces in reducing the effects of vibration on operations should be undertaken. Recommendations concerning how this may be achieved are tendered.

5. Whole-Body Vibration

Whole-body vibration may affect subjective comfort, working efficiency and in the worst cases, health and safety. Although there have been many methods for rating the severity and defining the limits of exposure to whole-body vibration, none has been universally accepted. Early work suggested that exposure to vibration as low as 0.1 Hz to 1.0 Hz should be limited.[95] Different methods have been suggested for determining the effect of complex vibrations as compared to sinusoidal vibration. Schoenberger[96] suggested that the independent component method of estimating the effect of complex vibrations would underreport the accelerations, and recommended the use of a weighting technique to predict the severity of complex vibration environments based on frequency bands. Other researchers agreed that the weighted method of predicting acceleration was inadequate to estimate the amount of discomfort produced in subjects.[97,98,99] Shoenberger's[100] further work in this area refined the ISO weighting method for predicting accelerations, and determined the role of angular accelerations in human response to vibration by using a subjective intensity scale to compare response to translational and angular accelerations. He noted that subjective human response to vibration was dependent on both the intensity and frequency of the stimulus, and suggested that seating configuration, type of seat, and type of restraint system are significant factors in determining exposure criteria[101]. Rotational vibration has also been found to produce discomfort in subjects, and various methods of alleviating this discomfort, such as foot rests or altering seating position, have been studied.[102] Translational vibration has been found to interfere with the use of manual controls.[103]

Although we are referring to whole-body vibration, in fact, vibration can be transmitted to the human body in a number of ways. First, as the name suggests, vibrations may be transmitted to the whole body surface simultaneously. Second, they may be transmitted to parts of the body surface such as the feet, or in the case of a seated crewmember, the buttocks. Third, vibrations may be applied to individual parts of the body. In addition to the method of transmission, other environmental factors such as the position may determine human response to vibration.[104] Harrah and Schoenberger[105] evaluated the effect of body angle on subject's subjective responses to vibration, finding that varying the subject's position shifted the area where the subject reported discomfort. Martin et al.[106] suggested that subjects altered their learned postural responses to wave motion in the presence of novel vibration stimuli, possibly leading to an increase in motion-induced task interruptions and workplace injuries. Vibrations can also affect human performance indirectly by affecting the stability of objects in the operator's visual field, such as viewing visual display units which themselves may be vibrating. This causes blurring of vision and difficulty of interpretation. Griffin[107] determined the minimal limits of vibration causing blurred vision, but noted that it differed with the subject's posture, the position of the head, the seating arrangement and usual task. He further noted that the motion of the retinal image may or may not share the same axis as the vibration stimulus and may appear to be circular or elliptical.

In terms of whole-body vibration, this can conveniently be classified as either low frequency motion induced by sea conditions surrounding the vessel and vibrations of higher frequency originating from the engines, propeller shafts, and major pieces of onboard machinery. Higher frequency vibrations can also originate from hull responses following severe slamming in heavy seas.[108] Early work in low-frequency vibration suggested a model of estimating subjective responses of equal intensity from 0.25 Hz to 4 Hz, useful for predicting performance at levels below that producible by most simulators.[109] Other researchers suggested that due to high variability in response to vibration across subjects, human response to vibration should be matched by ranges of equal sensitivity.[110] The range of maximum human sensitivity to vibration occurred in the range of 6-8 Hz, using this model.[111] In general, whole-body vibration in the range from 2 – 12 Hz can have an effect on human performance.[112] Sinusoidal vibration in the range of 3-8 Hz affects manual control through physiological pathways, as opposed to interfering with the operational performance of manual control.[113] Force cues as a means of feedback were suggested by Lewis and Griffin as a way to improve tracking performance involving manual controls. Even below that frequency range, however, Colwell[114] reported that there were significant manual control problems during simulated surface effect ship motions in the range of 0.02 to 0.2 Hz, where the vertical RMS magnitudes were 0.5 to 1 g.

The effects of whole body vibration are many and various. They may cause performance deficits, fatigue, accident-proneness and even health hazards. Nevertheless, the picture is not absolutely clear, and there are many differences of opinion on the effects of whole-body vibrations. It is not only dependent on many variables, but as Griffin pointed out in 1990, there is no one simple predictor for all individuals and every occasion.[115] This is certainly a matter that should be addressed in the design of new vessels, and in the installation of new equipment upon vessels. Due to the effect of whole body vibration on fine motor skills, this specific detriment requires further study to minimize performance degradation during shipboard tasks.

Recommendations

In light of the above findings, it would seem imperative that future efforts should be directed towards a comprehensive evaluation of the vibratory patterns inherent in the JCC(X) and how they may impact human operators aboard such vessels. These evaluations should include recorded data from various locations on prototypical vessels. Given this information, realistic simulations of vibratory environments can be implemented to study the effects on numerous aspects of performance in human subjects. Both perceptual and motoric capabilities should be investigated with a view toward evaluating various techniques that might be expected to ameliorate these adverse effects. Such techniques might include:

a) Modifications to the manipulanda employed in relevant at-sea tasks;
b) Dampening of man-machine and device-platform interfaces;
c) Optimal on-board locations for specific tasks;
d) The potential for human adaptation to vibratory environments.

These efforts will provide important guidelines for confronting the vibratory effects of existing vessels and will also yield information of value for ship design and modification.

Chapter 5 Additional Figure

Figure 97 from ASTM F-1166[116]

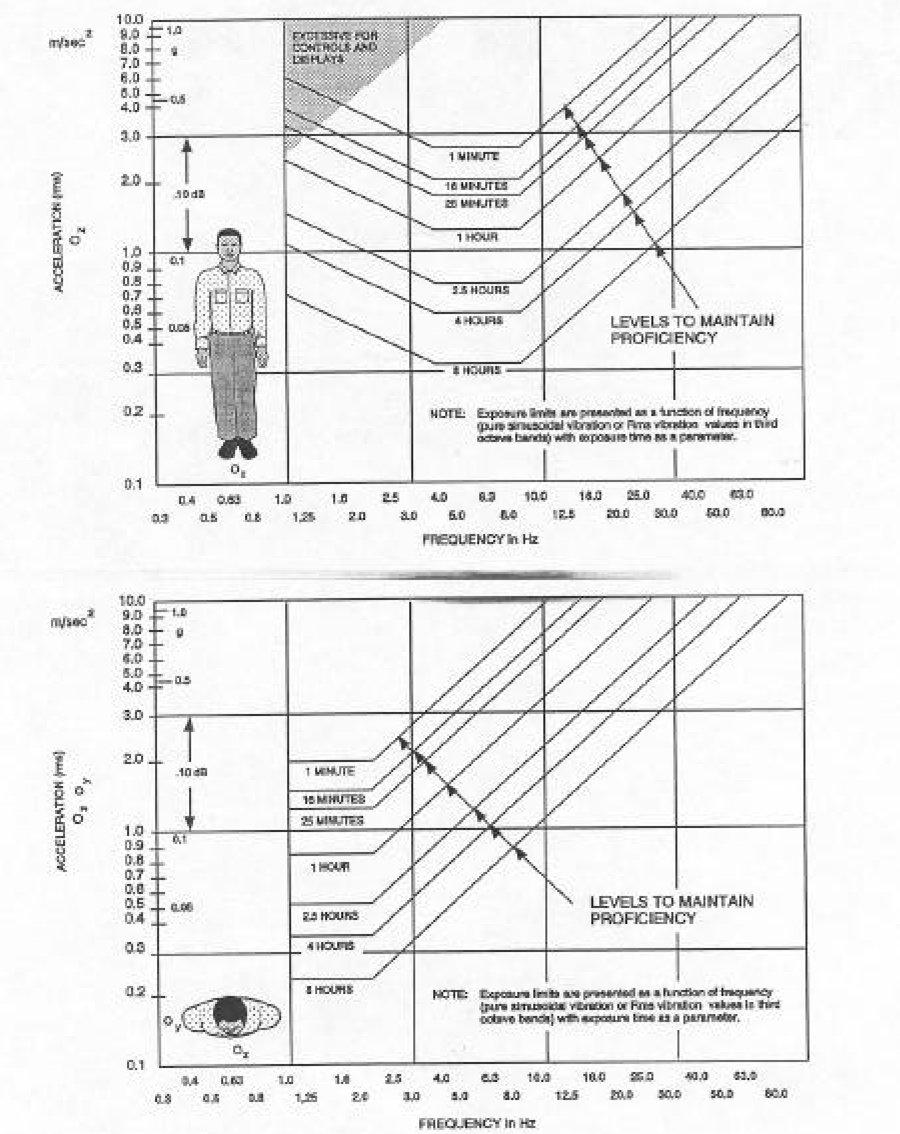

FIG. 97 Vibration Exposure Criteria for Longitudinal (Upper Figure) and Transverse (Lower Figure) Directions with Respect to Body Axis

Note: - When comfort is also essential then the acceleration value shown should be divided by 3.15 for the times and frequencies indicated.

- For safety considerations whole body vibration shall not exceed twice the acceleration values for the times and frequencies indicated.

6. Gross and Fine Motor Skills

Executive Summary

It has long been recognized that various ship motions can compromise the ability of human operators to carry out gross and fine motoric activities that are essential for successful and efficient operations at sea. It is important, therefore, to examine the degree to which specific motion profiles associated with the ships in question lead to these sorts of problems, not only directly (physically) but also indirectly thorough sleep loss and fatigue. Recommendations concerning such evaluations are suggested.

6. Gross and Fine Motor Skills

In any discussion of whole-body motion and whole-body vibration in the shipboard environment, much of the significance lies in the effect of these provocative stimuli on gross and fine motor skills. Typically these stressors interact to interfere with performance. For example, it is more difficult to carry out tasks requiring gross motor skills in a moving environment than in a static environment. The decrement of performance will vary with a number of factors. First, the severity of the hull/sea interaction, the weight and complexity of the components which call for performing a gross motor task, and the experience of the individual, both in carrying out the task and in standing and working on a moving platform. Ship motion may directly interfere with performance by interrupting the task, or it may indirectly interfere with gross and fine motor skills by affecting motivation or fatigue.[117]

Fine motor skills may be affected by vibration (see brief on vibration), ship motion or both in combination. Study of the effects of ship motion and/or shipboard vibration leads to a consideration of the type of controls being used onboard ship, whether these involve a keyboard, mouse, trackball or a touchscreen, and whether or not the operator's arms are supported or unsupported. In 1980, McLeod and Poulton[118] carried out a study of the influence of ship motion on manual control skills. They found that the response to motion while carrying out various tasks ranged from "virtual destruction" to a complete absence of adverse effects. In that study, they examined three manual control tasks which included: movement of the unsupported arms, continuous fine movement during which the arms were restrained, or ballistic manual tasks with an unsupported arm. They found that a tracking task that called for a continuous whole arm movement was, not surprisingly, very badly affected. In the case of a tracking task using fine movements with supported arms, this was affected but not significantly. Lastly, the ballistic task involving digit keying was virtually unaffected. These were relatively short duration tasks so that fatigue and what might be called chronic motion sickness (motion sickness symptoms over long periods) were not involved. They suggested that it would be beneficial to try to design the man-control interface onboard ships around motion-resistant tasks. Some evidence exists for the incorporation of a visual reference or artificial horizon to improve fine motor performance, but this may be related to effects of motion sickness, and is not yet conclusive.[119]

Gross motor skills in the presence of ship motion are subject to adaptation. While the effect of vibration on gross motor skills is less than that on fine motor skills, the introduction of novel vibration stimuli can cause the breakdown of learned postural adaptation to ship motion.[120] The development of seakeeping criteria for the minimization of effects of gross motor skills has long been of interest to ship designers. Key to the understanding of ship motion effects of gross motor skills in the concept of motion-induced interruptions. When the motion of the ship interferes sufficiently with the performance of the task to cause the tasks to not be completed or to be completed inaccurately, this is defined as a motion-induced interruption (MII). Motion-induced interruptions can be caused by a loss of balance, referred to as a tipping MII, or by longitudinal displacement from the target on the ship platform, referred to as a sliding MII. In 1990, Graham[121] suggested seakeeping criteria based on the number of motion-induced interruptions as predicted by a frequency-domain model further refined by Graham et al. in 1992.[122] Graham et al.[123] proposed a method for estimating sliding incidents under wave motion. Sliding MII play less of a role in performance degradation than tipping MII, due to the coefficient of friction of most ship surfaces[124]. Individual adaptation and compensation for motion also play a part in avoiding MIIs, which cannot be explained by a rigid-body model of MII occurrence.[8] Other studies of MII have suggested that ability to anticipate and compensate for motion decreases with the complexity of the motion.[125] Frequency-domain models of motion-induced interruptions (both tipping and sliding) are being currently being evaluated with modern biodynamic equipment in an experiment at the National Biodynamics Laboratory. While crew performance aboard ship is the main area of concern, deployment of other vessels from ships and safe operability of these other vessels as they interact is a significant performance question as well. The effect on human performance may vary from the host vessel to other vessels such as helicopters or smaller boats, even though both vessels are responding to the same parameters of wave height, wind speed, etc.[126]

Motion can have an indirect effect on gross and fine motor skills through motion-induced fatigue, which can be caused either by an individual's compensating for motion effects and increasing energy expenditure or by sleep disturbances due to motion.[127] Practical models discriminating between peripheral and central fatigue effects on gross and fine motor skills are needed.[128] Motion induced fatigue may be affected by hormonal and physiological factors in addition to the energy expenditure and metabolic energy costs associated with compensating for ship motion.[129]

Many researchers call for the study of gross and fine motor skills over a longer time period. Studies of this kind could identify the role of fatigue, sleep disturbance, motion sickness and adaptation to motion in the time course of performance decrements.

Recommendations

With representative ship motion profiles recorded at sea on prototypical JCC(X) vessels, laboratory simulations in which MIIs and fine motor perturbations are measured could certainly provide valuable information about potential problems with various operational tasks. In addition, with this approach, various counter measures involving different manipulanda, deck coatings, supporting arrangements and artificial horizons could lead to suggestions for the amelioration of such disruptive events. Trial duration could be manipulated to differentiate the degree to which direct motion effects (mechanical interruptions) and indirect effects (sleep loss and fatigue) contribute to these events. The degree to which gross and fine motor performance improves with adaptation and learning is also of great interest and could be studied with repeated exposures to provocative ship motion profiles. Data from such simulations could provide valuable guidelines concerning the likelihood of various types of gross and fine motor interruptions under various sea states given the characteristic response of the vessels in question.

7. Noise Effects

Executive Summary

> *Noise is an important concern in human performance in many working environments and shipboard work sites are no exception. Thus, appropriate R&D consideration should be given to the potential noise sources and ways in which these adverse effects can be reduced. The effects of such noise on human performance should be evaluated to determine the degree to which various types of noise are problematic on a JCC(X) platform.*

7. Noise Effects

As Jones[130] pointed out, sound is critically important to the well-being of the human being since the spoken word underlies communication, knowledge and culture. However, the human ear has been overburdened in recent years with the advent of industry and its wide variety of machinery. Unfortunately, much of the sound that we now hear is contaminant and it is this aspect of sound that we now recognize as noise. We are all well aware that hearing loss can result from long term exposure to intense noise, so it is most important to protect an individual's hearing from damage. This can be achieved by a combination of three basic precautions. First, by modifying the sound source in order to reduce the noise output. Second, by changing the transmission pathway so as to reduce the level of noise at the ear. Third, by reducing the duration of exposure to a potentially hazardous noise level or by providing personal protective equipment and ensuring that it is correctly fitted and worn in a noisy environment. In terms of performance, noise can certainly have a profound effect on verbal communication that is both distracting and annoying. Intermittent noise is more distracting than continuous noise and high-pitched noise is more distracting than low. In addition, noise that is non-localized is more annoying since the listener cannot turn away from the direction of the sound in order to hear better. In certain naval environments at night, crewmembers could be described as being "environmentally blind and deaf" since, in noisy work areas, it is very difficult to hold prolonged conversation over a distance of 1 meter if the noise level reaches 78 dB.

Communication methods and devices have traditionally relied on audiovisual modes to convey the message from a source to a recipient. These are capable of conveying considerable amounts of information within a reasonable time period with acceptable accuracy. A lesser known and relatively uncommon mode of communication is tactile communication. A tactile communication device (TCD) has been proven capable of communicating numbers to users with visual and hearing impairments and a control group.[109] If advances in the TCD result in the ability to perceive complex messages, the outcome could be a silent and non-vision-dependent communication system. The discrimination of four numbers with little or no practice suggests the possible development of a watch or pager system with the TCD. If the alphabet or other symbols can be perceived haptically, the perception of complex messages may be possible.

The non-auditory effects of unwanted noise are less well-defined. In general terms, they seem to act as a non-specific stressor, which means that in a shipboard multi-stress environment it can be difficult to identify those effects that are specifically due to noise rather than other stressors that are also present. In terms of overall performance, however, noise alone can have an insidious effect by inducing fatigue and stress.

In terms of these non-auditory effects, Poulton[131] observed that noise has "two quite distinct effects upon a person", namely, those of distraction on the one hand and arousal on the other. Distraction is most likely to adversely affect functions that call for prolonged continuous attention. Increased arousal may be beneficial in the performance of uninteresting routine tasks, since the individual tries harder and performs better. If the level of arousal is too high, however, the person may try too hard and performance becomes degraded. The theoretical inverted U-curves relating to performance and arousal are sometimes called the Yerkes-Dodson law.[132] As mentioned above, intermittent noise is more distracting than continuous, since it causes distraction and the receiver is less likely to adapt to this type of noise. Poulton[133] addressed the issue of the effects of continuous intense noise on performance. He pointed out that Stevens[134] had concluded that noise has no direct harmful effects on man, apart from producing deafness and annoyance. Later, workers, however, demonstrated that continuous noise significantly degraded performance. Poulton was adamant concerning the suggestion that continuous intense noise masks auditory feedback and inner speech and that this could account for all of the deterioration in performance caused by continuous noise. However, Broadbent,[135] who was one of the distinguished researchers in that field, rebutted Poulton's notion that the effects of noise were due to acoustic masking. Broadbent emphasized that there are three harmful effects of noise on skilled performance. First, a reduction in the detection of visual signals reported with risky criteria of judgment. Second, an increase of inefficiency, which causes errors or sometimes slow responses. Third, the tendency to concentrate on certain parts of a complex display at the expense of others. These are potentially serious degradations of performance that play an important part in command and control situations.

Broadbent[136] had previously reported on the effects of noise on paced performance and vigilance using a 5-choice serial reaction task that was "paced" or "unpaced", in a monotonous environment with no time cues, as used for a vigilance task. In general, he noted that the error rates were significantly higher during exposure to noise and only started to show after 5 minutes of exposure. Broadbent[137] also reported impaired performance "when watch-keeping on a display made up of steam-pressure gauges, in 100dB. noise as compared with 70dB." On the other hand, subjects who carried out a simpler task that consisted of watch-keeping on a display made up of small lights, showed no overall effect of noise. However, in this easier task, some evidence of a reduction in performance began to appear as the duration increased, while parts of the task continued to be performed adequately, others were not. Broadbent concluded that noise effects are functions of individual differences, signal visibility and duration of performance.

Corcoran[138] carried out two experiments to compare performance under continuous 90 dB white noise, after loss of sleep, under both of the conditions and under suitable control conditions. In these experiments, the noise, acting as an arouser, reduced the decline that would normally be expected with the loss of sleep, on the basis that noise is arousing and sleep loss is de-arousing. As previously pointed out by Broadbent[139], the effects of both loss of sleep and noise tend to occur towards the end of experimental exposures. It was, as expected, towards the end of Corcoran's experiments that he found that "noise became beneficial to sleep deprived performance." He did point out, however, that Hood[140] reported that "the intensity of sound reaching the more central areas of the central nervous system declines in time." That would suggest that the arousal feature should be stronger earlier, rather than later. Corcoran concluded that this kind of noise did not lose its arousing effects, however, and might even become greater over time.

Hockey[141] carried out a study to examine the effects of loud noise on the performance of a combined tracking and multi-source monitoring task. Each subject was tested twice, both in noise (100dB.) and "quiet" (70dB.). He found that the primary tracking task improved in the noisy environment as did the detection of the signals located centrally in the monitoring task. On the other hand, the light-signals that were located peripherally in the multi-source monitoring task were detected less frequently in noise. He interpreted these results in terms of increased selectivity of attention when aroused due to the noise, supporting the hypothesis that loud noise affects behavioral selectivity. Hockey[142] then examined the effect of changing the distribution of the light signals across the monitoring display that he used in the previous study. He found that there was no differential effect of noise for central and peripheral signal locations when there were equal numbers of signals at all locations, unlike his previous results when central signals were seen to have greater probability. He concluded that it is the high experienced probability of a signal that is important and not its central location.

Jones[124] discussed the question of the interaction of noise with other stressors to see if there was a common mechanism, acting either synergistically or antagonistically. He pointed out that the effects of heat stress has a different effect to noise on serial reaction time, whereas there are similarities in the effect upon multi-component tasks, but in combination these effects were not found to interact. As previously noted, he stated that sleep loss and noise have been shown to be antagonistic. In terms of incentive and noise, their joint effects appear to depend upon how the incentive is given. Apart from the effect with sleep deprivation, Jones concluded that evidence of interactions between loud noise and other stressors is somewhat equivocal. In terms of efficiency, as assessed in the laboratory, the effects of noise are complex. The effect seems to depend largely on the particular task and the attitude of the individual.

Recommendations

Given the ability for noise to influence performance, and because it is a concern for health and safety reasons, it is important to evaluate the degree of noise and the location of noise sources aboard the JCC(X) vessels. Empirical determination of sound levels should be made at sea with accurate acoustic recordings. Any locations containing noise levels which exceed OSHA guidelines will require suitable sound attenuating treatment or personnel protective devices. With appropriate recordings of JCC(X) noise environments, simulations may be constricted to study the degree to which communication is disrupted and performance is compromised. These studies could also explore non-traditional modes of communication to circumvent noise pollution problems. In addition, the question of how noise might interact synergistically with other stressors is worthy of serious investigation

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